Ed Boyle
New York
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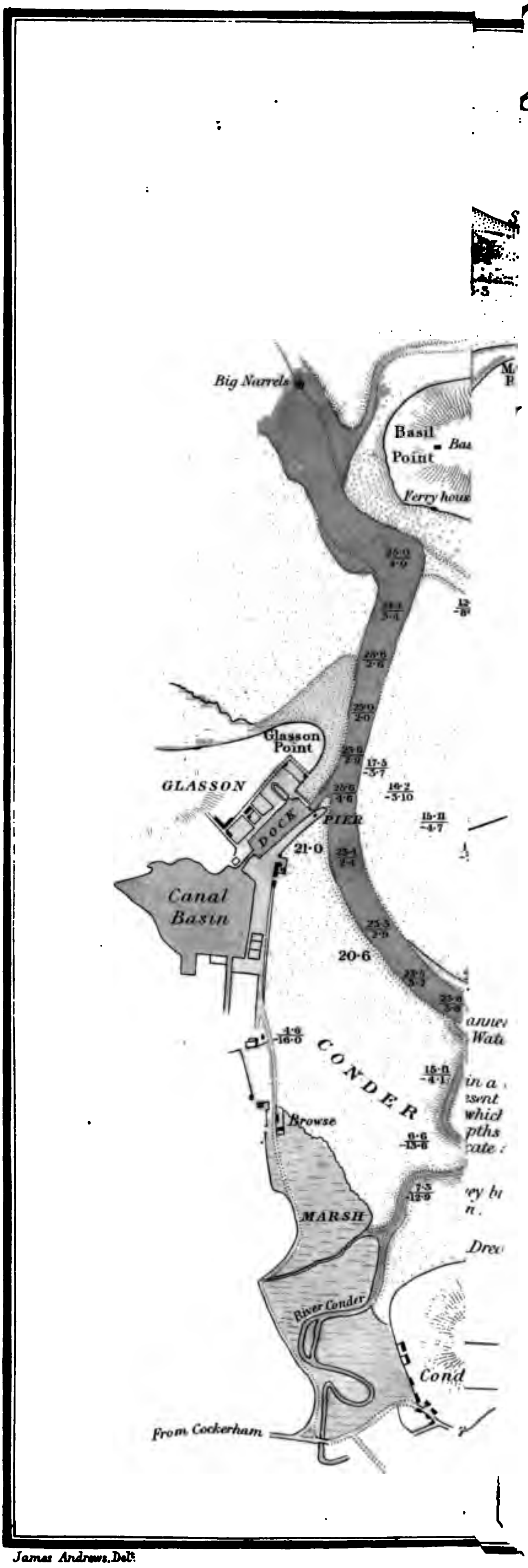
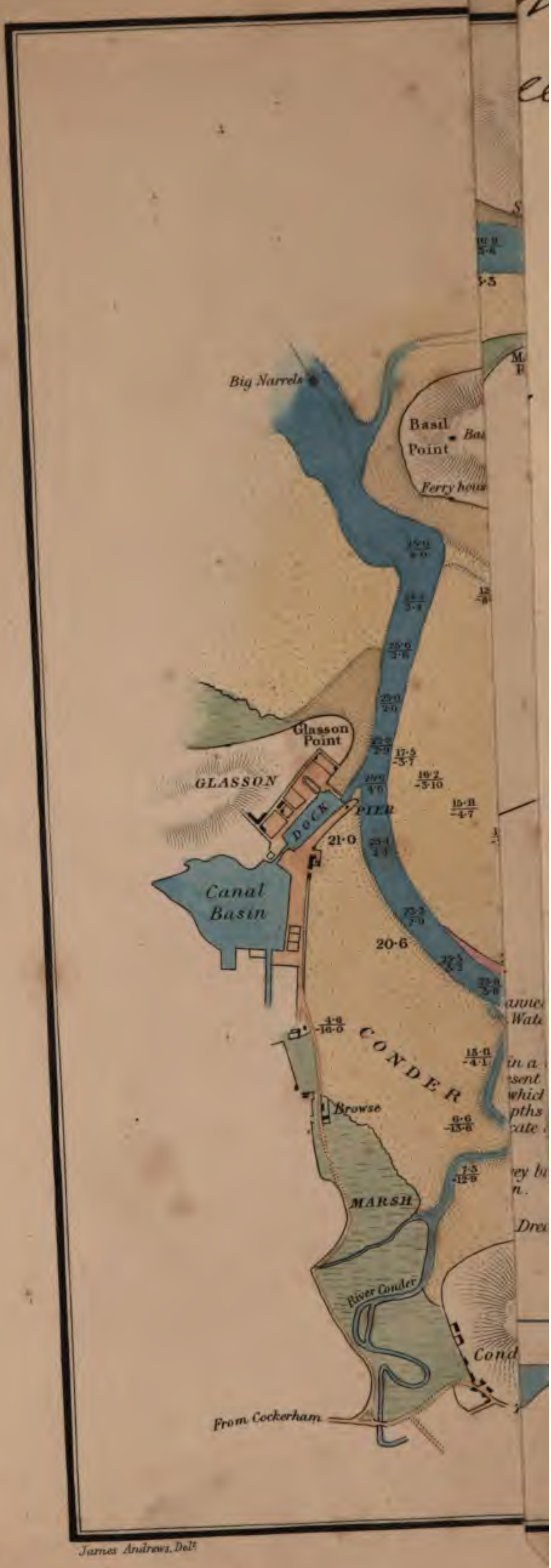
TREATISE

ON

MARINE SURVEYING & HYDROMETRY.



James Andrews, Delt.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James Andrews, Delt

Geo. Aikman, Sculp.t

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A

TREATISE

ON THE APPLICATION OF

MARINE SURVEYING & HYDROMETRY

TO THE PRACTICE OF

CIVIL ENGINEERING.

BY

DAVID STEVENSON,

CIVIL ENGINEER,

AUTHOR OF A SKETCH OF THE CIVIL ENGINEERING OF NORTH AMERICA, &c.

ADAM & CHARLES BLACK, EDINBURGH;
LONGMAN & CO., AND J. WEALE, LONDON.
MDCCCXLII.

PREFACE.

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Page 17, line 6, *for* 160° 29′ *read* 150° 29′

Page 131, line 11, *for* the natural sines of the whole, instead of half the angles, *read* double the natural sines of half the angles,

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The necessity of having accurate data on which to form designs for harbour and river improvements, or other hydraulic works, as well as to estimate their expense, will be readily admitted by all Engineers. It is, therefore, of great importance that those engaged in such inquiries, although

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PREFACE.

THE following Treatise is intended to afford a plain and detailed description of the "Application of Marine Surveying and Hydrometry to the practice of Civil Engineering," on which, it is believed, no work has hitherto appeared.

I have endeavoured to confine myself strictly to the consideration of the subject which is set forth in the title, without entering on an exposition of the principles on which the art of surveying is based, or giving a description of the construction and methods of adjusting and using surveying instruments, as these subjects have been already so fully treated of by others as to render any remarks on them quite superfluous.

The necessity of having accurate data on which to form designs for harbour and river improvements, or other hydraulic works, as well as to estimate their expense, will be readily admitted by all Engineers. It is, therefore, of great importance that those engaged in such inquiries, although

they do not actually conduct the operations of surveying, should be thoroughly acquainted both with the principles involved in them, and their practical application, so as to be able, not only to direct the attention of others to the best method of procuring the data required for Engineering investigations, but, if necessary, to acquire them for themselves.

There are many works which treat most fully and satisfactorily of the theory of surveying, but they appear to be generally wanting in directions for its practical application. On some departments of the art, such as making tidal observations, soundings, sections and borings, and conducting hydrometrical investigations, all of which are of the highest importance in Engineering inquiries, the works with which I am acquainted are either altogether silent or very inexplicit.

The present treatise has been written in the hope that it may tend, in some measure, to supply this want; and I have endeavoured to make it intelligible to those who are engaged in the study of the profession, as it is at an early stage of their progress that a knowledge of the subject treated of can be best obtained.

It is to be observed, however, that the reader is supposed to be already familiar with the art of surveying as generally taught, and with the use of the theodolite, sextant, and level,

which are the instruments employed. If information on these points be required, he is referred to any of the numerous published works on Trigonometry and Surveying, and, in particular, for a description of the instruments, to the very excellent treatise on that subject by Mr Simms.

The series of operations necessary in surveying a river embraces almost every point required in making any marine survey for Engineering purposes, and if all the steps of a river survey be thoroughly understood, no difficulty will be found in applying the system recommended in the following pages to a harbour survey including part of a line of coast, or to any similar case. I have, therefore, in order to simplify the subject, confined my observations principally to the details of river surveying, noticing, as they occur, such points as require further explanation with reference to the survey of a harbour, or of a line of coast. As it is difficult, however, to find any one case in which good illustrations of all the different departments of surveying are combined, the examples given are selected from the surveys of different rivers, according as they seemed best adapted to the object in view.

I have also made some observations on the manner of protracting the field work, and given an example of a finished plan, which may prove useful to the reader.

It may be proper to state, that the observations contained

in the following chapters have been thrown together, at intervals of leisure from more urgent duties, and are chiefly the result of a pretty extensive experience obtained in the course of surveys which were either at an early period conducted by myself, or have latterly been made under my directions.

I take this opportunity of expressing my obligations to Richard Ellison of Sudbrooke Holme, Esq., for his kind permission to refer to the Fossdyke navigation; and for similar favours I am indebted to the liberality of the Perth Harbour Commissioners, the Directors of the Ribble Navigation Company, and the Commissioners of St George's Quay, Lancaster.

DAVID STEVENSON.

EDINBURGH, *Feb.* 1842.

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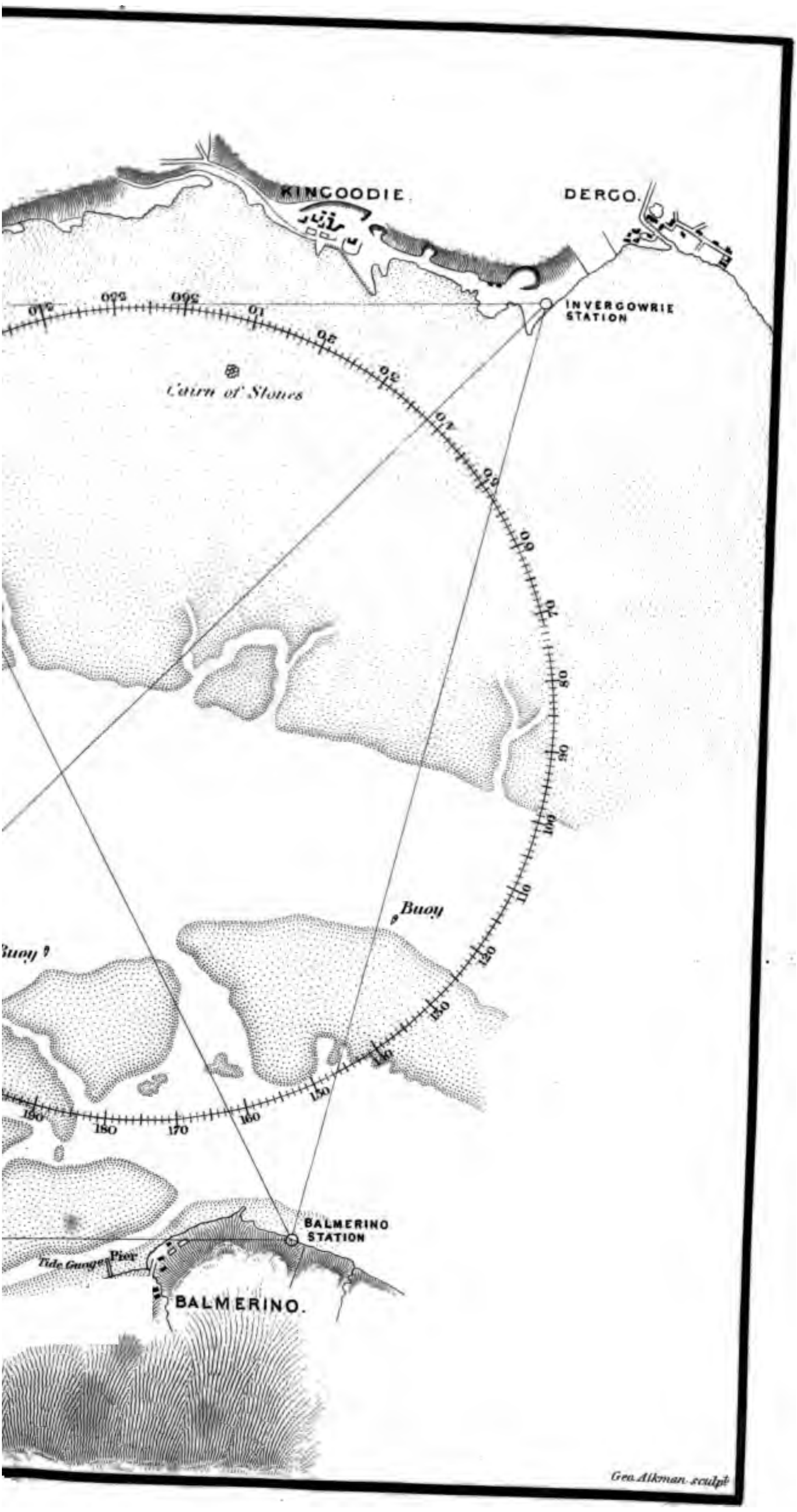

KINGOODIE.
DERGO.
INVERGOWRIE STATION
Cairn of Stones
Buoy
Buoy
BALMERINO STATION
Tide Gauge
Pier
BALMERINO.
Geo. Aikman sculpt

TREATISE.

CHAPTER I.

TRIANGULATION.

Selection of Stations—Conditions required to constitute a good Triangulation—Difficulties in selecting Stations—Poles—Flags—Arrangement of Colours of Flags, &c. for distinction—Reference to the Magnetic North—Local variation—Examples of local variation in Surveys—Its effect—Construction of a Compass for the plan—Selection of the Stations from which to determine the Magnetic North—Points to be kept in view in adjusting the Theodolite for observation—Mode of observing and registering the Bearings—Example of Field Book—Rule for adjusting Instrument at the succeeding Stations—Parallelism of the same Bearings at different Stations—Reverse Readings—Rule for reducing reverse Bearings.

The triangulation is the first operation to be performed in making the survey of a river; of which, indeed, it may be said to form the groundwork. It consists, as is no doubt already known to most of our readers, in the selection of certain well defined points on the banks of the river, called Stations, and the determination of the relative positions of those points by angular observations. Considerable judgment is necessary in selecting these stations; and the bearings by which their positions are determined must be taken

with great accuracy, more particularly as they are afterwards to be employed as objects for observation in laying down the positions of sunken rocks, sand banks, and soundings of the depth of water, and in making the survey of the margin or banks of the river; departments of the field work which will be more particularly explained hereafter, when the various uses to which the triangulation stations are to be applied will be fully illustrated.

Before attempting to fix the positions of any of the stations, the observer should walk along the whole extent of the river to be surveyed, examining first the one bank, and then the other. The object of this perambulatory survey is to make himself master of the general configuration of the shores or banks of the river, that he may be the better able, from actual knowledge of the ground, to fix the stations so as best to fulfil the several conditions required to constitute a good triangulation; on which, as may be inferred from what has already been said, the accuracy of the other departments of the survey, as well as the ease with which they are made, chiefly depend. The conditions referred to are,

First, That the triangles formed by the imaginary straight lines joining the adjacent and opposite stations be as nearly as possible equilateral.

Second, That from each station there shall be visible as much of the ground to be surveyed, and as many of the other stations, as possible.

Third, That the stations be not so far distant from each other as to render it inconvenient to employ them as points of observation in determining the positions of the sand-

banks, rocks, soundings, or other objects which require to be laid down.

Fourth, That the stations be as few in number as possible, consistently with the foregoing conditions. And,

Fifth, That each station be so chosen as to allow the theodolite, or other angular instrument, to be placed in correct adjustment over the spot occupied by the station-pole; which, as will be afterwards seen, must admit of removal for that purpose.

The fulfilment of these conditions may appear, at first sight, to be no very difficult task, for, in viewing the outline of a river as laid down in a chart or plan, the difficulties which have, in many situations, to be encountered, are not in their full extent discernible; but in practice, many obstacles present themselves, which experience alone enables the surveyor to overcome, and these impediments to the operations render the proper selection of the stations for the triangulation a work in which both care and judgment are required. Inequalities in the level of the banks of rivers, for example, often give rise to great inconvenience in selecting the stations. In some situations, the banks suddenly rise from a low flat to an abrupt head, having a considerable elevation, and projecting from the general line of the shore. When a corresponding elevation and projection take place in the opposite bank, producing a sudden contraction in the bed of the river (a formation of country not uncommonly met with), the triangulation may be said to be divided into two compartments, one on either side of the projecting heads; and it is often very difficult, in such a case, even by the best possible arrangement of the stations,

to connect these compartments in a satisfactory manner, either for want of a sufficient number of observations, or from the too great acuteness of the angles formed by the bearings taken from different points, by the intersections of which, the positions of the stations are determined. Again, when the river is broad, and the banks in the foreground are uniformly flat, with hills rising in the distance, much trouble often arises, in observing with the theodolite, from the difficulty of "picking up" the stations, if their positions are not selected and the colours of the flags arranged with reference to the circumstances and appearance of the background.

The configuration of the shores or banks of no two rivers being exactly the same in these respects, it is evident that no two triangulations, arranged in reference to particular cases, can be found exactly to agree, each being made to suit the peculiarities of the situation for which it was intended; and, therefore, no specific rules for the direction of the surveyor in the selection or arrangement of the stations can be given. In deciding on these matters, he must be guided by his own judgment, always keeping in view the five conditions already mentioned, and endeavouring, as far as possible, to fulfil them. I cannot pass from this part of the subject without remarking, that those who are inexperienced in surveying are very apt, in attempting to obviate some of the difficulties alluded to, to overlook the second last of the conditions to which I directed attention, and to adopt too many stations for their triangulation. This error should be carefully guarded against; for although the difficulties encountered may appear, at first sight, to be satis-

factorily overcome by increasing the number of stations, it will generally be found in the end that this desirable result cannot be obtained by resorting to such a measure. The adoption of this plan of overcoming obstacles, while it does not serve the purpose intended, introduces many serious evils; for not only is there a loss of time in fixing and making observations from each superfluous station, but, what is of much greater consequence, error and confusion, both in making the triangulation, and afterwards in fixing the low water lines and soundings, may be caused by the observer mistaking one station for another when they are thus injudiciously placed too near each other.

The truth of these remarks will be known to the experienced surveyor, who is alive to the importance of *reducing the chances of error in his work;* an object which must be the aim of all who would survey well. For it must be remembered, that in very few cases is it convenient to protract more than a very small part of the field work while a survey is in progress; and, therefore, it is proper that the surveyor should, in every step of his proceedings, pursue that course which insures the greatest chance of accuracy, that he may not have to go over any of the field work a second time; and, in compliance with this view, all his observations should be registered, and his field books kept in such a manner, that any one acquainted with this sort of work may be able to protract the survey from them.

When the river has been fully inspected, and the positions for the stations, after due consideration, determined on, the station poles are to be erected. The poles used in all the surveys with which I have been connected, were tapered

spars, of natural growth, measuring 4 to 5 inches in diameter at the large end, and from 15 to 25 feet in length, according to the situations for which they were intended. Flags of white or red cotton cloth, about 3 feet 6 inches in breadth, and from 3 to 5 feet in length, were fixed to the tops of the poles, for the purpose of rendering the stations more conspicuous. The poles were then firmly placed in a vertical position, their ends being sunk three or four feet into the soil, and a small mound of earth or stones heaped round them to keep them steady. In compliance with the last condition which was stated, care should be taken to place the poles so that, when removed in the course of the triangulation, the theodolite may be easily set with its vertical axis directly over the spot occupied by the pole. I am particular in directing attention to this point, having, on more than one occasion, seen a pole inadvertently placed in so injudicious a manner that it was quite impossible to adjust the instrument accurately, on its removal for that purpose. If any of the stations are situated near dwelling-houses, it is advisable to place them under the charge of the inmates, when they are disposed to take this trouble, as great inconvenience is often occasioned by their being carried off or destroyed by mischievous persons.

Generally speaking, one white flag is fixed to each of the poles, but sometimes two white flags, or a red and a white one, or two red ones, are placed on them, for the purpose of distinguishing them, when it is feared, from the direction in which they are to be viewed, or from any other cause, that the stations may be mistaken for one another. This precaution is often necessary, and I have in many cases found

it to be indispensable. The most secure way of fixing the flags to the poles, is to have a piece of stout cord doubled and strongly sewed into one end of the flag, so much of the cord being left extending beyond the edges as is necessary for tying the flag to the pole. The upper part of the pole, for the distance of 6 or 7 feet from the top, ought to be cleared from protuberances and smoothed, to prevent the flag from being caught by it during high winds and torn. For the same reason, the cloth of which the flag is composed must be firmly *hemmed*, otherwise it will be gradually wasted away by every successive breeze of wind, until nothing but its ragged end, and the cord by which it is attached, are left on the bare pole. Objections have occasionally been raised to the use of flags for the purpose of distinguishing stations, owing to their being invisible when the wind blows in the line of the observer's vision. I certainly have, on some occasions, experienced inconvenience from this cause; but, on the whole, I have no hesitation in saying that the method of distinguishing the stations which has just been described is the best and most convenient I have yet tried. Baskets of wicker-work painted different colours, and other marks of a similar description, fixed on the poles, are recommended in preference by some. These I have tried, and where placed between the observer's eye and the sky, they are as well seen as flags, provided they present the same surface; but if the station be in a place where hills, or trees, or any other objects rise behind it, I have found no distinguishing mark equal to a flag, the motion of which in the air can be detected when all still bodies appear to be blended into one general mass. The use of a pocket telescope will be found

of great service in assisting the observer to "pick up" the stations when any difficulty exists, especially if the theodolite be not furnished with a detached telescope, which in the instruments generally employed for ordinary surveying is seldom the case.

These different points may, perhaps, be considered by some as too insignificant to be mentioned; but it is of the greatest advantage to attend particularly to such minutiæ; and those only who have once or twice lost a day's work from not doing so can fully estimate their importance. There are few things more annoying than to find that a day's work is lost owing to a flag on a principal station having been carried away, or to its injudicious colour or position having rendered it invisible; and if this be occasioned by the neglect of some of these seeming minutiæ, the annoyance is doubly harassing.

When the station poles have been set up, the observations of their bearings are next to be taken with the theodolite, or other angular instrumemt employed. That this may be done in a satisfactory manner, fine weather is necessary; if it blows hard, it is only a loss of time to attempt the operation, but there ought to be a light breeze, sufficient to blow out the flags so as to make them "shew," and also to carry away the slight haze which almost invariably accompanies calm weather. Bright sunshine is, generally speaking, by no means so favourable for the operation as a sky somewhat cloudy. If the weather should not be favourable for this purpose, some other part of the survey may be proceeded with; for the poles being fixed, the triangulation may be completed at any future time when most convenient.

But I shall follow out what may be considered the natural order, and describe what is necessary for completing the triangulation, before entering on any of the other departments of the survey.

The magnetic needle, independently of those changes which are ascertained to be constantly going on in its direction and dip, to which the term "variation" has been applied, is subject to other variations occasioned by local attraction, in consequence of which, it has, under certain circumstances, been found, that, in surveys even of limited extent, the magnetic north, as indicated by the needle, varies in its direction to a very appreciable amount at different stations. The causes of these variations are in some cases very apparent, but in others they are not so easily discovered, and therefore cannot be so well guarded against. I have met with many instances of errors in observations produced by local variation, some of which have given rise to considerable trouble, before the cause from which they proceeded could be detected. On the river Tay, for example, I found the variation on one occasion to amount to 2° 30′ in a distance of about a quarter of a mile. The first of the series of observations by which this local variation of the needle was discovered, was made on the top of a high bank, about 50 feet above the level of the water, and the second on a low tide-covered sand bank in the middle of the river; but the attracting influence could not, in this case, be satisfactorily ascertained. On another occasion, an error, amounting to no less than 7°, was introduced into the bearings of a survey, in consequence of certain observations which had been referred to the magnetic north having been made in the

vicinity of a large steam engine boiler, which lay concealed from view in a warehouse, close to which the instrument had been set, and the influence of this mass of iron on the data of the survey could not, at the time the observations were made, be avoided. In another instance an error of 2° was in like manner introduced into a harbour survey, owing to the instrument having been inadvertently set too near a cast iron mooring pall which was fixed on one of the quays. These facts seem sufficient to warrant the general conclusion, that the magnetic north, as indicated by the needle, should never be employed in surveying, as a check on the accuracy of the bearings of stations or objects; because its direction cannot be relied on as unalterable; and in accordance with this view the needle will be found to act a very subordinate part in the system of surveying which I have attempted to describe in this treatise.

It is absolutely necessary, however, that the positions of the stations in reference to the magnetic north should be determined as accurately as possible, in order that a magnetic meridian line may be applied to the survey from which a compass may be constructed, for, without this, the utility and value of the chart or plan to be made would, of course, be greatly diminished. In order to insure this, it is only requisite, in beginning the survey, to assume the magnetic north as indicated by the needle attached to the instrument, as the zero of the observations; and it is well to note the bearing of the magnetic north at the first three or four stations of the triangulation, for, in this way, any great local variation, similar to that in the cases already alluded to, which may happen to exist at any of the stations, will be

less likely to pass undetected. If the bearings of the north line are very nearly the same at all the stations at which it has been observed, the mean may be adopted as the magnetic meridian for the survey. It is proper that the true as well as the magnetic north should be shewn on the plan; but as the variation of the compass for almost every place in this country is known and has been ascertained far more accurately than can possibly be accomplished by any observations made by an engineer in the course of his investigations with an ordinary surveying theodolite, it is unnecessary in this place to describe the manner of determining it with that instrument. The compass constructed on the magnetic bearing taken in the manner described as a basis, with the line of true north, at the nearest place for which it has been determined, applied to it, is sufficiently accurate for all marine surveys made in the practice of civil engineering to which the system of surveying described in this treatise, as explained in the preface, is strictly limited.

The station at which the observations of the triangulation are commenced should be such that an extended view may be had, including distant objects within its range; for if it be selected in a contracted part of the river where the distance between the different objects to be observed is inconsiderable, there is much less probability of making so near an approximation to the truth in determining the exact position of the line of the magnetic north in reference to the survey. As an illustration of this, let us suppose that in the bisection of a station pole at a short distance, say 220 yards from the point of observation, an error of 2 inches has been made, arising partly from the poles not having been

placed perfectly perpendicular, and partly from the difficulty of effecting its accurate bisection. If the imaginary lines representing the true and the observed directions were produced beyond the observed station at which the error had been made, they would evidently continue to diverge, and the error would be gradually increased in direct proportion to the distance; and at the distance of say 6 miles, it would be found, in the case I have mentioned, to have increased from 2 inches to 8 feet. Now a space of 8 feet, which is nearly double the whole length of the flag attached to the poles, when viewed with a good instrument and under favourable circumstances at the distance of 6 miles, is a much more appreciable quantity in attempting to bisect a pole of say 4 inches in diameter, than a space of 2 inches, viewed under the same advantages, at the distance of 220 yards; and hence an observation made to a distant station is more likely to give a correct result in obtaining the magnetic line for the survey than one taken to a near object. The way in which this angular divergence affects the results of a survey is obvious, for in the case of commencing the triangulation at the broadest part of the river any error made in the angular observations may be said to be the *maximum* error of the survey, its effect in throwing the points out of their true position being gradually decreased as the distances between the stations decrease; but if the triangulation be begun at the narrowest part of the river, any error that is made may in that case be called the *minimum* error of the survey, and will be gradually increasing as the survey extends, so that at the broadest part of the river the amount of angular divergence from the true line may, as already shewn,

be very great. This cause of inaccuracy, which is so easily obviated, should be strictly guarded against in surveying; for if an error be found to exist in the direction of the magnetic meridian, it is impossible to decide whether it is due to the cause I have endeavoured to explain, or is to be imputed to variation produced by local attraction; a doubt which, of course, precludes correction.

The only other consideration to be attended to in the selection of the stations from which to observe and determine the magnetic north is, that they shall be free, so far as can be ascertained, from the agents which cause local attraction; a remark, the force of which will be apparent to all from what has been already said on that subject. Sometimes, no doubt, these sources of error, as has been shewn, exist in forms which prevent their presence from being readily discovered, and for this the surveyor has no remedy; but still stations which present apparent agents, such as the immediate vicinity of an iron work or steam engine, or even a mass of trap rock, ought to be avoided.

I have throughout supposed the reader to be familiar with the use of surveying instruments, and therefore I shall only make three remarks regarding the adjustment of the theodolite for observation, with reference to points, which some, who are able to use the instrument, are apt to overlook. In the first place, the station pole ought invariably to be removed from its place to make room for the instrument. It is not sufficient to push it to one side, as is sometimes done. In the second place, the instrument should be set exactly over the spot which the pole occupied, and by the help of the adjusting plummet attached to the theodolite,

its axis will be easily made very nearly to coincide with what was formerly the axis of the station pole. And, in the third place, the instrument should be very carefully *levelled* before beginning to observe, and care taken that the levelling plate screws are not again touched till the observations are completed. All of these remarks being kept in view, and the instrument having been adjusted with 360° bearing north, as indicated by the needle, the observations may be commenced.

The observer ought then to take the bearings of all the stations within view, as well as of all conspicuous marks on the banks of the river, such as spires, chimneys, or any prominent and well defined objects, which may afterwards be useful, as points for observation, in laying down the positions of the soundings and sand banks. In taking these observations, he should begin at zero or 360° (which are identical), and go regularly round the horizon. It is proper to take the objects to be observed in regular succession as they come into view, that none of them may be omitted, and that there may be as little occasion as possible for moving the instrument. When the observations have been completed, a bearing should again be taken to the first station observed, to ascertain whether the reading be the same as that registered in the field book; and if this is found to be the case, the lower limb of the instrument may be presumed to have remained stationary during the operation, and the observations may be held as accurate.

The theodolites used for such surveys as I am describing have generally two verniers, placed at opposite points of the horizontal limb. At these the angles may be read off only

to degrees and minutes, smaller angular quantities being disregarded. If an instrument reading to seconds be employed, the exact bearing may be noted, as it will be useful if any of the triangles are to be calculated; but for ordinary surveys this refinement is unnecessary, as angular quantities, which are smaller than one minute, cannot be appreciated in protracting the work. It is proper, however, in all cases, to read off and register the bearings given by both verniers, as the one reading serves as a check on the other. They will occasionally be found to differ a minute in the reading, and in that case the mean may be taken as the true bearing, if great accuracy is required; but this, as will afterwards appear, is of no practical consequence in protracting the work.

The following is the manner in which the observations ought to be registered, and, like all the other examples I have given, the angles are taken from the field book of an actual survey.

Angles at Balmerino Station, River Tay, 8*th August* 1833.

	Vernier A		Vernier B	
	°	′	°	′
North magnetic,	360	0	180	0
West chimney of Birkhill House,	80	40	260	40
Flisk station,	90	4	270	4
Randerston station,	101	20	281	21
Errol Church spire,	105	23	285	23
Seaside station,	110	56	290	57
End of red-tiled house, Powgavie,	117	24	297	23
Powgavie station,	128	46	308	46
End of plantation,	141	32	321	31
Monorgan station,	148	20	328	20
Invergowrie station,	189	34	9	34

	Vernier A		Vernier B	
	°	′	°	′
Invergowrie chimney, ...	190	30	10	31
Dundee Law, ...	233	26	53	26
Dundee Church Tower, ...	246	51	66	52
Ferryness, ...	268	58	88	59
Newport Inn, ...	274	12	94	12
Small house in Wormwort Bay, . .	283	30	103	30
Magnetic north, ...	360	0	180	0

The positions of most of these stations will be seen on referring to Plate I., which is a sketch shewing a small part of the triangulation of the river Tay, in which they occur. When the bearings have been taken, the station pole is again erected in its place and carefully plumbed, and the observations from the other stations may then be proceeded with.

Referring to the same example, we shall suppose that the next station from which observations are to be made is Flisk. The field book must then be consulted to ascertain what was the bearing of Flisk from Balmerino. It is found to be registered on the other page under vernier A as 90° 4′. That vernier is then set and clamped at 90° 4′, and the instrument having been directed to Balmerino station, the observations are taken and registered as follows:—

Angles taken at Flisk Station, River Tay, 8th August 1833.

	Vernier A		Vernier B	
	°	′	°	′
Balmerino station, ...	90	4	270	4
East Balmbrich station, ...	270	14	90	13
Balmbrich Castle, ...	268	30	88	30
River Earn station, ...	276	9	96	9
Mugdrum Island station, . . .	273	30	93	30
West Port Allen station, ...	278	53	98	54

	Vernier A	Vernier B
	° ′	° ′
East Port Allen station, . .	283 40	103 40
Randerston station, . . .	296 25	116 26
Church of Errol, . . .	299 57	119 57
Seaside station, ...	330 26	160 29
End of red house, Port Allen, . .	348 56	168 57
End of plantation, . . .	30 4	210 4
Monorgan station, . . .	37 40	217 40
Invergowrie station, . . .	55 20	235 21
Dundee Law, ...	70 14	250 15
Dundee Church Tower, . . .	77 57	257 58
Birkhill, ...	96 14	276 13

We shall suppose the next place from which observations are to be taken to be Seaside. In adjusting the theodolite at this station, the surveyor has a choice of adopting either the bearing from Balmerino or from Flisk, as that to which he is to set the vernier. In the event of adopting Balmerino, the vernier would be set at 110° 56′ (the bearing of Seaside from that station), and the instrument directed to Balmerino. In adopting Flisk it would be set at 330° 26′, the instrument being directed to that place; and in either case the bearings would be taken in the manner already explained.

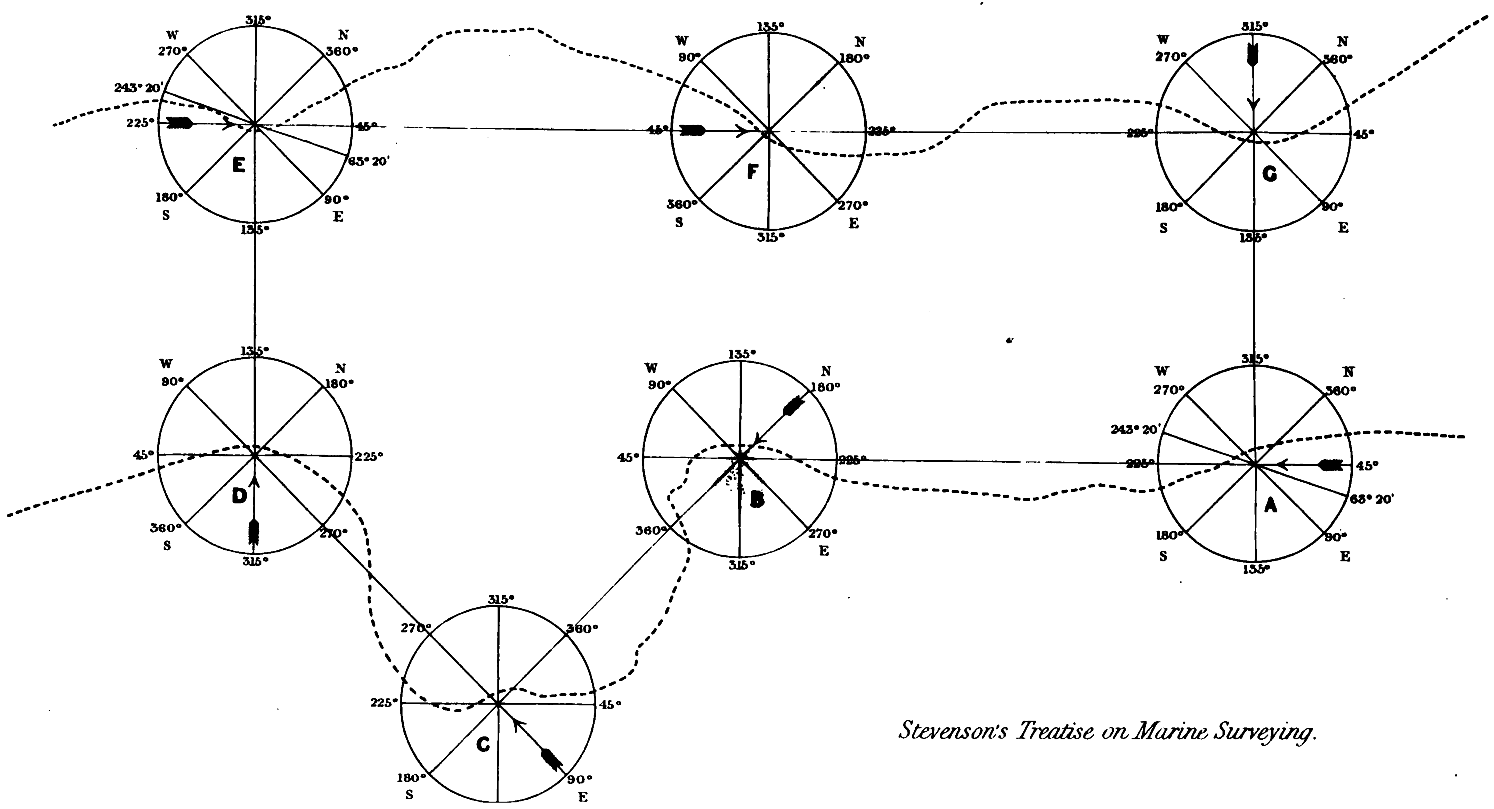
In this way the angular bearings to prominent objects from all the triangulation stations on the river are to be carefully taken and registered.

The following general rule may be given for adjusting the theodolite, as shewn practically in the foregoing examples: Suppose the observations are to be taken from a station which we may call *z*, the surveyor may adopt, as the primary bearing for setting the instrument, the angle

which *z* bore from any other station in the survey, as *w*, *x*, or *y*, from which *z* had previously been observed (provided the situations of those stations render them equally applicable), the theodolite being, in every instance, directed to the station the bearing of which has been used.

By following the system which has been described, it is obvious that all the corresponding bearings throughout the whole of the triangulation will be parallel to each other, whatever be the position of the station from which they are taken. For example, the lines bearing 360°, 45°, 90°, and 135°, or N., NE., E., and S.E. by compass, at all the different stations, will be parallel to each other, and of course all the intermediate bearings of the same name will be parallel also. This may perhaps be rendered more clear by a reference to Plate II., in which the irregular dotted lines are supposed to represent the outline of a river, and A, B, C, D, E, F and G, stations placed on its banks; the circles representing, on an exaggerated scale, the horizontal limb of the theodolite, when adjusted at the different points. At station A, 360° is set at the magnetic north, as indicated by the needle. The bearing of B from A is then found to be 45°, and in setting the instrument at B, the station A is made to bear 45° from it also. In like manner the bearing of C from B is 180°, and that of B from C is made the same. The reader will trace this throughout the whole of the stations to G. A simple examination of the diagram will shew, that if the triangulation is correctly constructed in accordance with the rules laid down, the corresponding bearings throughout the whole, as already stated, will be parallel to each other.

Diagram illustrative of the Triangulation.



Stevenson's Treatise on Marine Surveying.

One point has still to be noticed. It will be observed that the bearing from A to G is 135°, but that the bearing from G to A is 315°. This, although a different reading, is actually the same bearing, as appears very obviously from the diagram, the variation in the reading being occasioned by the limb of the instrument having been turned round 180°. Every bearing may, in this way, be said to have two readings at opposite points on the limb of the theodolite; and the original and its opposite bearing are read alternately. Thus, if we represent the stations of a triangulation by the letter A, affixing numbers in the order in which the observations were made at them, calling the first A_1, it will be found that all those having *even* numbers as A_2, A_4, A_6, A_8 &c., will give the same bearings *to* station A_1, as those taken *from* it, and all those having *odd* numbers, such as A_3, A_5, A_7, A_9 &c., will give the opposite bearings to A_1. In checking the bearings of different stations to ascertain whether the work has been accurately done, some difficulty may arise to the inexperienced, especially if the theodolite has only one vernier, by finding this variation from a bearing formerly taken and registered. If the instrument has two verniers A and B, and if the reading vernier A does not indicate the same bearing as that formerly registered, the original bearing will be found on examining the vernier B. But if there be not two verniers, the rule for discovering whether the work be right is easily applied, and is as follows. Suppose a reading, as from G to A, plate II, does not correspond with the bearing taken on a former occasion from A to G, then if the angle read is *above* 180° deduct 180° from it, and it will give the former bearing; if it be 180° or

below 180° add 180° to it, and the same result will b tained. Thus the bearing from G to A = 315° − 180° = = the bearing from A to G; and again, the bearing A to E is 63° 20′ + 180° = 243° 20′ = the bearing from A. It will be obvious to all, that the foregoing observa have reference to an instrument whose reading limb i vided into 360° and not into twice 180°, the former divi being preferable, and now almost universally adopted.

CHAPTER II.

BASE LINE.

Most desirable Length for a Base Line—Requirements for insuring an accurate measurement—Process of Measuring—Methods of determining the extremities of the Base—Three cases described, first when the Line extends between two triangulation stations; second, when it is an independent Line but connected with the triangulation by a back bearing; third, when it is measured on a sand bank and unconnected with the triangulation—Methods to be pursued in these different cases described.

THE process described in the former chapter is entirely one of angular not of linear measurement; and although it affords the data for determining the relative positions of the different stations and objects on the river, it does not give the means of ascertaining the linear distances between them in terms of any measure, as yards or miles. It furnishes, in fact, merely a representation or map of the relative positions of the objects, intersected by the lines of observation, without affording a scale, which can be determined only by the actual measurement on the ground of a base line; an operation which forms the subject of the present chapter.

The actual measurement of the fundamental base line, and the observations for the determination of its length in reference to the distances between the triangulation stations,

cannot occupy too much care and attention, as the accuracy of the scale of the survey, and consequently of all the linear dimensions on the plan to be constructed, depends entirely on the correct execution of these important operations.

Most of our readers are, no doubt, aware of the extreme care and labour which have been bestowed on the operation of measuring the great fundamental base lines for the trigonometrical survey of the country, a subject which has given rise to much practical and theoretical discussion; and although, in surveying for engineering purposes generally, the same degree of accuracy is not required, and is indeed quite inappropriate, as well from the time which must be devoted to it as from the means employed in its attainment, still the surveyor, bearing in mind the importance that is attached to this department in surveys of greater extent, ought, in his own practice, to use every means in his power to make as near an approximation to the truth as possible.

The length of the base line to be adopted is the first consideration to which the attention of the surveyor ought to be directed. In deciding on this point, he must be regulated partly by the extent of the survey to be made, and partly by the formation of the country. A line extending from three quarters of a mile to a mile and a quarter in length will be found sufficient for most engineering surveys. But, it may be stated as a general rule, that it is advantageous to adopt as long a base line as the circumstances of the situation will admit of, taking care, however, that the limits I have mentioned be not greatly exceeded, and, at the same time, keeping in view that the angles from the extremities of the base to the other stations may be favourable

for connecting it with the survey. It is often only with great difficulty, however, that even this limit in regard to the length of the base line is attained, and it can very rarely be exceeded in ordinary river surveying, owing to the difficulty, in most situations, of obtaining a stretch of ground of sufficient extent possessing all the necessary requirements to insure accuracy in the measurement.

The requirements alluded to may be comprehended under three heads, all of which the surveyor ought to keep in view in selecting the situation for the base line.

In the first place, the surface of the ground ought to be smooth, and without inequalities, so as to admit of the measuring chain being fully and properly stretched, on which the accuracy of the result may be said chiefly to depend. Secondly, although the base may be measured on regularly rising ground, which, in conformity with the first requirement, has a smooth surface, still it is more desirable that the site of the line should be as nearly level as possible: for if one extremity of the base is on a much higher level than the other, it is necessary that the difference of height be accurately ascertained by the spirit-level, in order that a correction may be applied for the error in actual horizontal length, produced by measuring along the hypothenuse instead of the base of a right angled triangle. This operation involves a considerable consumption of time, and ought, if possible, to be avoided, by selecting a level line. It is very seldom necessary, however, to resort to it in surveying a river; for if the formation of its margin should be such as to preclude the possibility of selecting a situation on the land free from the disadvantage of an irregularity in its

level, a nearly horizontal plane, of sufficient extent, is, in most cases, afforded at low water by some of the sand banks in its bed or estuary. Thirdly, the two poles used for marking the extremities of the base ought, if it can possibly be attained, to be visible from every point of the line, as this greatly conduces to the ease and accuracy with which the work is done, saving the trouble of putting in intermediate poles, and the chance of error in consequence. This requirement is generally easily attained when the site of the base is on a sand bank; but when it extends along the margin of the river, fences and other obstructions occasionally intervene, and cause much trouble in effecting an accurate measurement. I mention this circumstance as the evil may often be avoided, by using a little care in selecting the site.

When a situation for the measurement of the line, fulfilling these three requirements, and extending between two of the triangulation stations, can be obtained, it should at once be adopted, as both the field work and the protraction are thereby greatly facilitated; and although, in order to simplify the subject, the attainment of this desirable object was not introduced in the preceding Chapter as one of the conditions necessary for making a good triangulation, yet it should not be overlooked in fixing on the sites of the triangulation stations. It is often, however, no doubt, very difficult to pitch upon two points possessing the necessary requirements for good triangulation stations, and at the same time having a clear stretch of ground extending between them, in all respects suitable for making an accurate measurement; and when this union of qualities cannot be pro-

cured, the base line may be placed, as already hinted, either on a level sand bank or marsh, so situated that favourable angles may be obtained from the principal stations on the river for fixing its extremities with accuracy, and connecting the measured distance with the triangulation of the survey. The nature of the observations required for this purpose merits a little attention, and will be noticed hereafter.

In the mean time it may be remarked in reference to any situation that may be adopted, that the method of procedure in measuring the line is the same in all cases. Rods formed of wood, glass, and other materials, as well as chains of a peculiar construction, are employed in the measurement of base lines when a very near approximation to the truth is required; but for surveys of the kind described in this treatise the measure or rule employed is the common surveying chain of 100 feet in length. The chain of 66 feet, although exceedingly useful, and even indispensable, in land-surveying, from its being divided into links, is, from this very circumstance, by no means so convenient as the 100 feet chain for engineering surveys, in which the whole of the dimensions are referred to a scale of feet. From the nature of its construction, the chain, on being stretched, is very liable to yield to a small extent at the junction of each link, and its length is thus often gradually increased by use. It should, therefore, be carefully compared with some known standard, and, if necessary, properly adjusted before being employed in the measurement of the base line. But if this be inconvenient, it will answer equally well to compare it with the standard, after the operation has been completed,

and before it has been used for any other purpose, and if found too long, an addition, proportional to the amount of error, must be made to the length of the base.

The persons employed in measuring the line ought to have some experience in the use of the chain. Care should be taken that it be properly stretched, and that the marking pins be placed with exactness by those who "drive" and "lead" it. It is also of importance that the exact line of direction be kept with the greatest possible accuracy, as any variation from it causes an increase in the measured length.

The distance should be ascertained at least three times, or oftener if necessary, otherwise no check on its accuracy is obtained; and the person who "drove" the chain during the first measurement, ought to "lead" it during the second. If the maximum difference between the results be found not to exceed 3 feet, the third measurement being intermediate between the other two, the operation may be considered as sufficiently accurate for ordinary purposes, and the mean of the three results should in that case be adopted as the length of the base line of the survey.

When the base line extends between two of the triangulation stations, which, as already noticed, is the most convenient situation that can be adopted, the points referred to in the foregoing remarks are all that demand particular attention; but in reference to those cases where the line is situated on a marsh or sand bank, some remarks are still necessary relative to the observations which are required for fixing the positions of the extremities of the base, and connecting the measured distance with the triangulation of the survey.

The surfaces of marshes and sand banks are, in general, smooth and flat, without any great diversity of level, and are, on this account, very favourable for making an accurate measurement; but as they are generally covered by the tide at high water, it is often difficult, and sometimes impossible, if they are on a very low level, to complete the whole operation of measuring the line, and taking the observations for fixing its extremities in one tide; which, if it can be accomplished, is, for many reasons, desirable. When the marsh or sand bank on which the measurement is to be made has been selected, and the situation of the line, in reference to the triangulation stations, has been duly considered and fixed on, a small surveying pole, having a flag attached to it, should be placed at one extremity of the base; and a similar pole should be set up in the direction in which the measurement is to be made, and at such a distance from the first as may be considered a proper length for the line. The distance between the poles should then be ascertained in the manner already described; and as it will, in all probability, prove to be a quantity which is not easily divisible, a correction to convert it into an easily divisible quantity may be made in a very simple manner. Thus, if the length be 8007 feet, a quantity into which it would be difficult to divide any given space, one of the poles should be moved back 7 feet, and the length of the line reduced to 8000 feet; a quantity into which any space on a plan may, if necessary, be easily and accurately divided for the purpose of making a scale. The utility of this correction will be better understood when we come to treat of the protraction, to facilitate which it is intended.

It is evident that if an observation be taken from one of the triangulation stations to the pole at either of the extremities of the base line, and if this observation be used as the primary bearing in taking the angles for ascertaining the position of the line, the bearings so taken will accord in parallelism with those of the triangulation; and the site of the base line might thus be laid down by the means employed in protracting the triangulation itself, which will be particularly described hereafter. When the base line poles, therefore, are so situated that they may be allowed to remain for some time, even though exposed on a marsh or sand bank, without danger of being carried away by the tide, and all traces of their positions lost, it is proper that the observations for determining their positions should be made in this way. But it is sometimes necessary, and has indeed happened in my own experience, that in order to obtain a proper base line, they must be placed on a low sand bank, covered to a considerable depth at high water, and situated in the midde of a channel or estuary, perhaps 5 or 6 miles in breadth, where it would not be safe to allow the stations to be overflowed, with the expectation of their remaining unchanged; and, therefore, as the whole operation connected with the measurement has to be completed in one tide, there is not, in such circumstances, sufficient time for ascertaining the bearing of the poles from any of the triangulation stations. If there were no local attraction, the magnetic needle might, in this case, be again referred to. But, from what has already been said on this subject, it will be seen that its direction cannot be relied on. Indeed, the first instance of variation, mentioned at page 9,

occurred on a sand bank in attempting to make observations for fixing the extremities of a base line in this manner, being quite analogous to the case at present under consideration. One of the stations of the triangulation ought, therefore, to be taken as zero; and the theodolite should be set, and the observations made, in the following manner. The instrument being clamped at 360°, the telescope is to be directed to the station which has been assumed as zero; after which, the bearings of all the stations within view are to be taken and registered; and the same operation having been repeated at the other end of the base line, it will be found that sufficient data have been obtained for accurately determining its position, as will appear more evidently hereafter in treating of the Protraction.

CHAPTER III.

TIDE OBSERVATIONS.

Remarks on the Tides of Rivers—Variations in the Tidal Lines—Professor Robison's remarks as to the anomalies of River Tides—Explanation of the exact nature of the inquiry into the Tides which is to be instituted—Selection of Stations for Tide Observations—Agents which produce disturbance in the parallelism of the Tidal Lines—Description of Tide-Gauges to be used—Points to be kept in view in fixing them—Method of fixing them on Sloping Beaches—Method of keeping the Time—Method of making Observations—Form for registering Observations—Description of Form—Ascertaining the relative Levels of the Gauges—Points to be kept in view in levelling for this purpose.

THE tides of rivers are influenced partly by the circumstances under which the great tidal waves of the ocean enter their mouths or estuaries, and partly by the size of the streams and the configuration of the beds and banks of the rivers themselves, all of which have a share in modifying the free flow of the tidal currents along their channels. As no rivers are to be met with whose communication with the sea, and the course and strength of whose streams are in all respects similar, corresponding dissimilarities naturally occur in the circumstances attending the rise and fall of river tides. A thorough and accurate investigation of this

subject forms a very important part of the marine department of a river survey; and the method of conducting it, as applicable to the object of engineering surveying, will now be described. The observations contained in the preceding chapters may be said to apply to the art of surveying generally; but many of the remarks to be made regarding tidal observations, soundings and sections, refer solely to such investigations as are instituted in reference to purely engineering questions, and are consequently inapplicable to other purposes.

If it were correct to assume that the high water mark of each tide, at any given number of points in a river's course, stood invariably on the same level,—that the times of high water at these points were the same,—and that the progressive rise and fall of the tides were uniform and equal at every point,—or, in other words, that the lines formed by the surface of the water at all periods of flood and ebb, which we shall in future denominate the tidal lines of the river, were parallel to the line of high water,—the work of the surveyor would be greatly simplified. But if the engineer were to make such an assumption the groundwork on which to found his opinions and frame his designs, his conclusions would almost invariably be formed on erroneous data; and in many instances the consequences might be very serious.

In no river, so far as I am aware, are the high water lines of every tide perfectly level, or the tidal lines invariably parallel; and observations made in reference to these points, in some situations, give results which are very anomalous, and which would very materially affect the accu-

racy of the soundings and sections of a river, if they were not distinctly ascertained, and the necessary precautions taken to avoid the errors to which they would inevitably lead.

The following remarks by the late eminent Professor Robison,* illustrative of the causes of some of the anomalies in river tides, are interesting in connection with this subject.

Regarding one of the anomalies to which I have alluded, namely, the rise or inclination which often occurs in the high water line, from the entrance of a river upwards, the Professor makes the following observations :—" When a wave of a certain magnitude enters a channel, it has a certain quantity of motion, measured by the quantity of water and its velocity. If the channel, keeping the same depth, contract its width, the water, keeping for a while its momentum, must increase its velocity or its depth, or both, and thus it may happen, that, although the greatest elevation produced by the joint action of the sun and moon in the open sea does not exceed 8 or 9 feet, the tide in some singular situations may mount considerably higher. It seems to be owing to this that the high water of the Atlantic Ocean, which at St Helena does not exceed 4 or 5 feet, setting in obliquely on the coast of North America, ranges along that coast in a channel, gradually narrowing till it is stopped in the Bay of Fundy as a hook, and there it heaps up to an astonishing degree." Again, as to the variation in the times of high water at different points, and the non-parallelism of the tidal lines, the same eminent individual makes

* Robison's Mechanical Philosophy (Brewster's Edition), vol. iii. p. 353.

the following remarks:—" Suppose a great navigable river, running nearly in a meridional direction, and falling into the sea in a southern coast. The high water of the ocean reaches the mouth of the river (we may suppose) when the sun and moon are together in the meridian. It is therefore a spring tide high water at the mouth of the river at noon. This checks the stream at the mouth of the river, and causes it to deepen. This again checks the current farther up the river, and it deepens there also, because there is always the same quantity of land water pouring into it. The stream is not perhaps stopped, but only retarded. But this cannot happen without its growing deeper. This is propagated farther and farther up the stream, and it is perceived at a great distance up the river. But this requires a considerable time. We may suppose it just a lunar day before it arrives at a certain wharf up the river. The moon at the end of the day is again on the meridian, as it was when it was spring tide at the mouth of the river, the day before. But in this interval there has been another high water at the mouth of the river, at the preceding midnight, and there has just been a third high water about 15 minutes before the moon came to the meridian, and 35 minutes after the sun has passed it. There must have been two low waters in the interval at the mouth of the river. Now, in the same way that the tide of yesterday noon is propagated up the stream, the tide of midnight has also proceeded upwards, and thus there are three co-existent high waters in the river. One of them is a spring tide, and it is far up at the wharf above mentioned. The second, or the midnight tide, must be half way up the river, and the

third is at the mouth of the river. And there must be two low waters intervening. The low water, that is, a state of the river below its natural level, is produced by the passing low water of the ocean, in the same way that the high water was. For when the ocean falls below its natural level at the mouth of the river, it occasions a greater declivity of the issuing stream of the river. This must augment its velocity; this abstracts more water from the stream above; and that part also sinks below its natural level, and gives a greater declivity to the waters behind it. And thus the stream is accelerated, and the depth is lessened in succession, in the same way as the opposite effects were produced. We have a low water at different wharfs in succession just as we had the high waters."

"This state of things, which must be familiarly known to all who have paid any attention to these matters, being seen in almost every river that opens into a tide way, gives us the most distinct notion of the mechanism of the tides. It is a great mistake to imagine that we cannot have high water at London Bridge (for example), unless the water be raised to that level all the way from the mouth of the Thames. In many places that are far from the sea, the stream at the moment of high water is down the river, and sometimes it is considerable. At Quebec it runs downwards at least 3 miles per hour. Therefore the water is not heaped up to a level, for there is no stream without a declivity."

In the river Amazon, the tide is said to ascend against the stream, in the manner described, for several days, and to penetrate to the distance of 200 leagues from its mouth, seven or eight tides, with intermediate low waters, following

each other in succession ;* and in the Thames we find a similar tidal succession, but not to so great an extent, and arising, according to Mr Whewell, "from the peculiar circumstance of the river's having a tide compounded of two tides arriving by different roads, after journeys of different lengths," in allusion to the two branches into which the tidal wave is divided on reaching the British shores, one of which flows up the English Channel, while the other proceeds along the west and northern coast of the country, and flowing down the east coast, again joins the other branch.

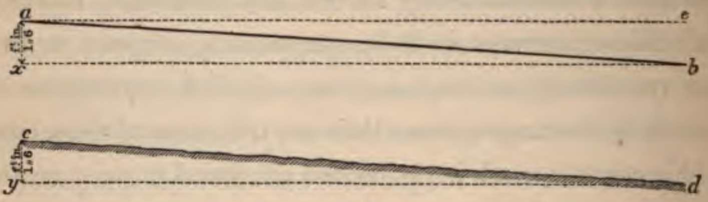
Such variations on the tidal lines as those described in the quotations from works of Professor Robison, would no doubt be found to exist in every situation, if the rise of tide and the capacity of the river or estuary were sufficiently great to admit of their full development, and if the observations made were of sufficient extent to include them within their range. But from the smallness of our rivers, which flow from a comparatively narrow and contracted country, the ordinary surveys made for engineering purposes in Britain very rarely embrace so great a field of observations as to include the range of more than one tide, nevertheless, even in this country, such irregularities are found to exist on the tidal lines as to require careful investigation to insure accuracy, especially in situations where the rise of tide is great.

Before entering fully on the explanation of the different steps to be taken in making a correct series of tidal observations, by which alone the anomalies I have alluded to can be discovered, some preliminary remarks, in explanation of the exact nature of the inquiry to be instituted, appear necessary to the proper understanding of what is to follow.

* Encyclopedia Britannica, art. River

If the tidal lines of a river were level and parallel, a series of observations on the progressive rise and fall of the tides (made in the manner described hereafter), at a single graduated gauge placed in any part of its course, at which the whole of the tidal rise and fall is developed, would afford sufficient data for obtaining a survey in all respects correct. If, on the other hand, the lines had a certain inclination, but were nevertheless parallel to each other, the single series of observations alluded to, would still be sufficient for obtaining the correct depths at high water, and consequently an accurate profile of the bed of the river, exhibiting all its inequalities; but it is evident that the inclination of the tidal lines, and, what is of more importance, the true position of the bed of the river in reference to the datum line of the section, could not be ascertained by this means. Thus let the lines *a b* and *c d* represent the high

FIG. 1.



water line and the bed of a river respectively, and let there be a rise of 1 foot 6 inches in both of them in the distance represented in the cut. If one tide gauge only were used, suppose at the lower extremity of the river, the section, when protracted, would assume the form represented by the dotted lines *x b* and *y d*, in which the high water line and bottom of the river are shewn as being level, whereas their

correct positions in reference to the level line *a e*, which we may suppose to be the datum line of the section, are those represented by the lines *a b* and *c d*, on each of which there is a rise of 1 foot 6 inches.

The inclination of the bed forms an important element in all questions relative to the navigation of rivers, and proper means must be adopted for its determination before any design of improvement can be formed. In order to ascertain this, it is obvious that at least two tide gauges must be used, one at either extremity of the river; and farther, that their relative levels must be accurately ascertained. Now, if the high water line in the case referred to in fig. 1. should stand at 10 feet on the lower gauge, it will, if their zeroes are at the same level, stand at 11 feet 6 inches on the upper one at the same moment, thus indicating the difference of level. In this way not only are the data for ascertaining the correct depths at high water afforded, but a proper section of the river can be made, its tidal lines and bed being represented in their true positions in reference to the datum line.

From what has already been said, however, regarding the anomalies of the tides, it will readily be seen that it would be improper to assume that the tidal lines are parallel during the whole period of flood and ebb; and therefore it is necessary, in surveying, to provide for this, by adopting intermediate stations for tide observations, and by taking the soundings of the river at particular periods when the deviation from parallelism in the tidal lines is at its *minimum*, as will be more particularly noticed hereafter.

In determining the number and selecting the sites of

the stations at which tide observations are to be made, the engineer ought to be regulated by the amount of tidal rise and the configuration of the banks of the river. In rivers where the rise of tide is small, and the tidal currents are very languid, fewer places of observation are required than in situations where there is a great rise of tide, accompanied by rapid currents, as the parallelism of the tidal lines, on which the correctness of the soundings depends, is less apt to be disturbed in the former than in the latter case. It may be stated as a general rule, that the more numerous the tide stations are, the nearer will the results obtained approximate to the exact line of the tidal wave at any particular moment of flood or ebb, and the less chance will there be of error in reducing the depths of the soundings. As, however, every additional station involves additional trouble and expense, and as great difficulty is often experienced in finding persons properly qualified to make the observations, it is generally necessary, in ordinary surveying, to reduce this part of the establishment as much as possible, and often to a greater extent than could be wished, adopting, in preference, the precaution of taking the soundings at those periods of tide when the deviation from parallelism is ascertained to be small, and in this way the want of a more extended system of observations is of less consequence. The only matter of regret in pursuing this course is, that so near an approximation cannot be obtained to the forms assumed by the tidal wave during flood and ebb, which is in itself a subject of great interest.

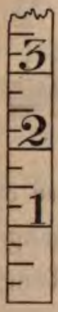
Whether an extended or limited series of observations is to be adopted, it is necessary, while selecting the sites for

the stations, to have due regard to the agents most likely to produce disturbance in the parallelism of the tidal lines. The most powerful of these agents are, abrupt turns or bends, and sudden enlargements or contractions in the transverse sectional areas of rivers. The irregularities which exist in the declivities of the beds of most rivers do not necessarily affect the parallelism of the tidal lines, and need not therefore, unless they are abrupt and high, influence the surveyor in selecting the stations, their only effect being to alter the vertical amount of tidal rise at the places where they occur.

When the sites of the stations have been finally determined on, which should be done at an early stage of the survey, the tide gauges ought to be erected, and the observations at the different places commenced without loss of time, in order that they may embrace as great a range of tides as possible, as the correctness of the results deduced from the observations of course depends on their number.

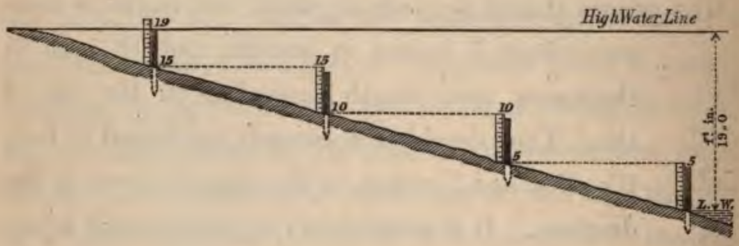
The gauges should be made of plank, and ought to measure about 7 inches in breadth and $1\frac{1}{2}$ inch in thickness, their length depending on the rise of tide. They should be accurately graduated to feet, 6 inches, and 3 inches, in the manner shewn in the diagram. It is unnecessary to graduate the intermediate inches, which may be easily measured by the eye; and when marked, introduce a needless complexity of graduation, apt to puzzle rather than to assist the ordinary class of observers. The gauges should be of a length sufficient to include the whole range of the highest tide from low to high water,

Fig. 2.



and should be so placed as to be easily seen at all times by the person who is to make the observations. The first of these desiderata can be best attained by making the gauge a few feet longer than the reputed maximum rise of tide at the station where it is to be fixed, and by placing 2 or 3 feet of it below the supposed low water line, it being a matter of no consequence at what point on the staff the low water stands. The second is often very easily accomplished by fixing the gauge beside a quay wall or an abruptly rising bank. But difficulty sometimes occurs when it is necessary to erect it on a gently sloping beach, where the surface, covered by the rise of tide, is so great as to render the figuring of the gauge, if placed at the low water line, indistinct, or perhaps altogether illegible, when viewed from the high water mark. I have on more than one occasion, under such circumstances, found it very convenient to divide the gauge into pieces, and

Fig. 3.



to fix them in the manner shewn in fig. 3. The rise of tide is here represented as being 19 feet; and the gauge is divided into four pieces, the upper mark of each being placed on the same level as the corresponding mark at the bottom of the piece above it. It is better to employ this

simple arrangement when it can possibly be done, than to put up the gauge in one piece, which, in such a situation as that alluded to, not only requires a very strong framework properly guyed for its support, but is liable to be carried away by the tide, while recourse must be had to the inconvenient method of using a telescope, in order to read the figures.

The gauges having been adjusted, the observations on the progressive rise and fall of the tide should be commenced. The persons employed to make them must be furnished with watches. It is difficult entirely to avoid variation in time at the different stations, and the only remedy for this is to visit the observers as often as possible, and, if necessary, to correct their time by reference to a pocket chronometer; the amount of error and the time when the correction was made being noted in the tide book. In this way the necessary allowance may be made for difference of time in comparing the observations at different stations, and in reducing the depths of the soundings. The observations should be made at intervals of not less than ten minutes, and should extend from six in the morning till six in the evening at least, and earlier or later when soundings are to be taken before or after these hours. It will be found to be a great convenience to employ printed forms for registering the observations of both the tides and soundings, and indeed of all the observations in surveying to which they can be applied. Annexed is a copy of the form I have been in the habit of using for registering those of the tides, which will best explain the mode of doing it. The example is taken from the River Lune.

REGISTER OF TIDES AT GLASSON PIER

Time.		Height.		Remarks.	Time.		Height.		Remarks.
H.	M.	Ft.	In.		H.	M.	Ft.	In.	
4	0				8	30	24	3	
	10					40	24	3	
	20					50	24	3	
	30				9	0	24	3	
						5	...	...	Tide began to appear.
	40					10	22	2	
	50					20	19	6	
5	0					30	17	5	
	10					40	15	9	
	20					50	14	5	
	30				10	0	13	3	
	40					10	12	3	
	50					20	11	3	
6	0	24	0	Wind SW. light.		30	10	0	
	10	24	0			40	8	6	
	20	24	0			50	7	4	
	30	24	0		11	0	6	0	
	40	24	0			10	4	10	
	50	24	0			20	3	9	
7	0	24	0			30	2	8	
	10	24	0			40	1	7	
	20	24	0			50	1	1	Calm.
	30	24	0		12	0	0	9	
	40	24	1			10	0	8	High Water.
	50	24	1			20	0	9	
8	0	24	1			30	1	0	
	10	24	1			40	1	5	
	20	24	2			50	1	9	

N.B.—The zero of the tide gauge in this example was placed

STATION, RIVER LUNE, 6TH SEPTEMBER 1838.

Time.		Height.		Remarks.	Time.		Height.		Remarks.
H.	M.	Ft.	In.		H.	M.	Ft.	In.	
1	0	2	2		5	30	22	10	
	10	2	11			40	23	1	
	20	3	7			50	23	4	
	30	4	4		6	0	23	6	
	40	4	10			10	23	7	
	50	5	11			20	23	8	
2	0	6	6			30	23	9	
	10	7	6			40	23	10	
	20	8	6			50	23	11	Wind SW. light breeze.
	30	9	6		7	0	23	11	
	40	10	6			10			
	50	11	6			20			
3	0	12	6			30			
	10	13	5			40			
	20	14	2			50			
	30	15	0						
	40	15	9						
	50	16	7						
4	0	17	7						
	10	18	5						
	20	19	0						
	30	19	6						
	40	20	4						
	50	21	0						
5	0	21	9						
	10	22	2						
	20	22	7						

RESULTS.

Greatest depth, ...24 ft. 3 in.
Greatest height,...... 0 8
Whole rise,...........23 7
Began to rise at ...... 9 h. 5 m.
High Water at ......12 h. 10 m.

above the level of high water, so that the gauge reads downwards.

The *first* column contains the time; the *second*, the height at which the water stood on the gauge; the *third*, is for remarks, and at the end are the results of the day's observation. The figures in black are those of the printed form, and those in red correspond to the figures entered by the observer.

It may be proper to mention, before leaving the subject of the apparatus employed, that, in river surveys I have never found it necessary to use glass tubes in making the observations, as the water has generally been comparatively calm; but in surveying exposed places, such as parts of the coast, in reference to harbours, I have found it indispensably necessary to employ this apparatus, to counteract the disturbing effect of the undulation of the surface of the sea, even in moderate states of the weather.

The next process to which I shall advert, is that of ascertaining the relative levels of the different gauges, for the purpose of determining the form assumed by the tidal lines. Advantage should be taken of calm weather for this purpose; and although it is only an ordinary levelling operation, yet, like everything else in which accuracy is indispensable, it requires attention, often absorbs a great deal of time, and probably ends in error if not conducted in a systematic manner. It is a nice operation to transfer a level accurately for a distance, varying perhaps from 6 to 30 miles or more, according to the extent of the survey; and while it is inexpedient to introduce too many refinements in performing the operation, it is necessary to insure expedition and accuracy that the following particulars be attended to. In the *first* place the whole distance must be levelled at least twice, and

any part of it that may be found erroneous, of course oftener. *Secondly*, the distance to be levelled should be divided into compartments of such lengths that each of them may be gone over twice in one day; and, in addition to this, bench-marks should be fixed at convenient intervals. *Thirdly*, a tripod, or, what answers the same purpose, a small peg of wood driven a few inches into the ground, on which to rest the levelling rod, should invariably be used where the soil is soft; and, *fourthly*, the distance at which the rod is placed from the instrument should be as nearly as possible the same in taking the fore and back sights, so as to neutralize the effect of the earth's curvature, and should not exceed 350 paces. By attending to these directions, the work will be greatly simplified; but it is nevertheless a tedious operation, and every improvement on the instruments used, or the system of levelling adopted, deserves attention. The latest improvements on the instruments of which I am aware, are those suggested by Mr Thomas Stevenson, who, in addition to the parallel plate screws, has introduced a ball and socket joint, and a small circular level, to facilitate the adjustment of the instrument, and certain screws for moving and clamping the vane of the levelling rod. By means of these improvements, as tested by experiment, a very great saving in the time at present consumed in adjusting the instrument is effected, and greater nicety in bringing the centre of the vane to coincide with the cross hairs of the instrument is obtained.

CHAPTER IV.

SOUNDINGS.

Nature of the variations on the Tidal Lines explained—Examples of the variations on the Dee in Cheshire—The Lune in Lancashire—The Forth in Stirlingshire—Manner in which these variations affect the Soundings—Reference of Soundings to one Datum Line explained—Half Tide Level not applicable in the case of Rivers—High Water of a certain Tide adopted—Use made of the Tide Gauges in reducing Soundings to the datum—Formula for their reduction—Example—Formula only true on the supposition of the Lines being parallel to High Water—Example in the case of the Dee—Results affected by the erroneous supposition—Mode of avoiding this by increasing the number of Tide Stations—but this not always attainable—General Rules for taking Soundings to approximate to accuracy—Method of taking Soundings described—Equal Distribution of Soundings over area of River—Observations for fixing their positions.

THAT any directions as to the best method of taking soundings, and avoiding inaccuracy in reducing them to high or low water, arising from the non-parallelism of the tidal lines, may be clearly understood and duly appreciated, it is necessary that the reader should know distinctly the nature of the variations adverted to, which are determined by means of the observations treated of in the preceding chapter; and also that he should be fully aware of the manner in which they affect the accuracy of the soundings, and the

extent of error that may, under certain circumstances, be occasioned by them. I shall, therefore, before entering upon what is, strictly speaking, the subject of this chapter, lay before the reader the results actually obtained by me in making some surveys for engineering purposes, as they will afford distinct practical information on the points alluded to, and, at the same time, be useful in conveying a correct idea of the nature of the data required in producing a complete marine survey.

The results which I shall state, in the first place, were obtained from observations made during the months of May and June 1839, in surveying the river Dee in North Wales, with reference to the improvement of its navigation.

In making the survey of that river, which extended from the Bridge of Chester to Flint, three series of simultaneous tide observations were instituted, one at Chester, another at a small village called Connah's Quay, and a third at Flint. The following were the results obtained from the survey.

The distance from Chester to Connah's Quay is $7\frac{1}{3}$ miles, and that from Connah's Quay to Flint $3\frac{2}{3}$ miles; the whole distance from Chester to Flint being 11 miles. The part of the river which extends from Flint to Connah's Quay may be said to be an open estuary; and the upper part, extending from Connah's Quay to Chester, is an artificial tidal canal, having an unobstructed water-way of about 500 feet in breadth at high, and 250 feet at low, water.*

* It was in this straight reach that Mr J. S. Russell made certain observations on the "Tide Wave of the Dee," the result of which he reported to the British Association in 1837.

The high water line was found, by an average of twenty-four observations, to rise 2 inches from Flint to Connah's Quay; and from Connah's Quay to Chester the rise was found to vary from 4 inches at neap to 14 inches at spring tides, giving, as the result of twenty four observations, an average rise of 6 inches. The whole average rise on the high water line from Flint to Chester is therefore 8 inches.

The difference between the times of high water at the different stations was found to vary very much, and appeared to be more affected by the state of the winds, or some other cause unknown, than by the circumstance of the tides being neap or spring; but the average of the observations gave the time of high water at Flint twenty minutes earlier than at Connah's Quay, and that of high water at Connah's Quay thirty minutes earlier than at Chester; the whole average difference in time between high water at Flint and at Chester being fifty minutes.

The average level of the low water line at Connah's Quay is 2 feet 6 inches below that at Chester, giving on the distance of $7\frac{1}{3}$ miles an average fall of 4.09 inches per mile, and the level of the low water at Flint is 7 feet 6 inches below that at Connah's Quay, giving on a distance of $3\frac{2}{3}$ miles an average fall of 24.54 inches per mile. The total fall from Chester to Flint is 10 feet, being an average fall on the distance of 11 miles of 10.9 inches per mile.

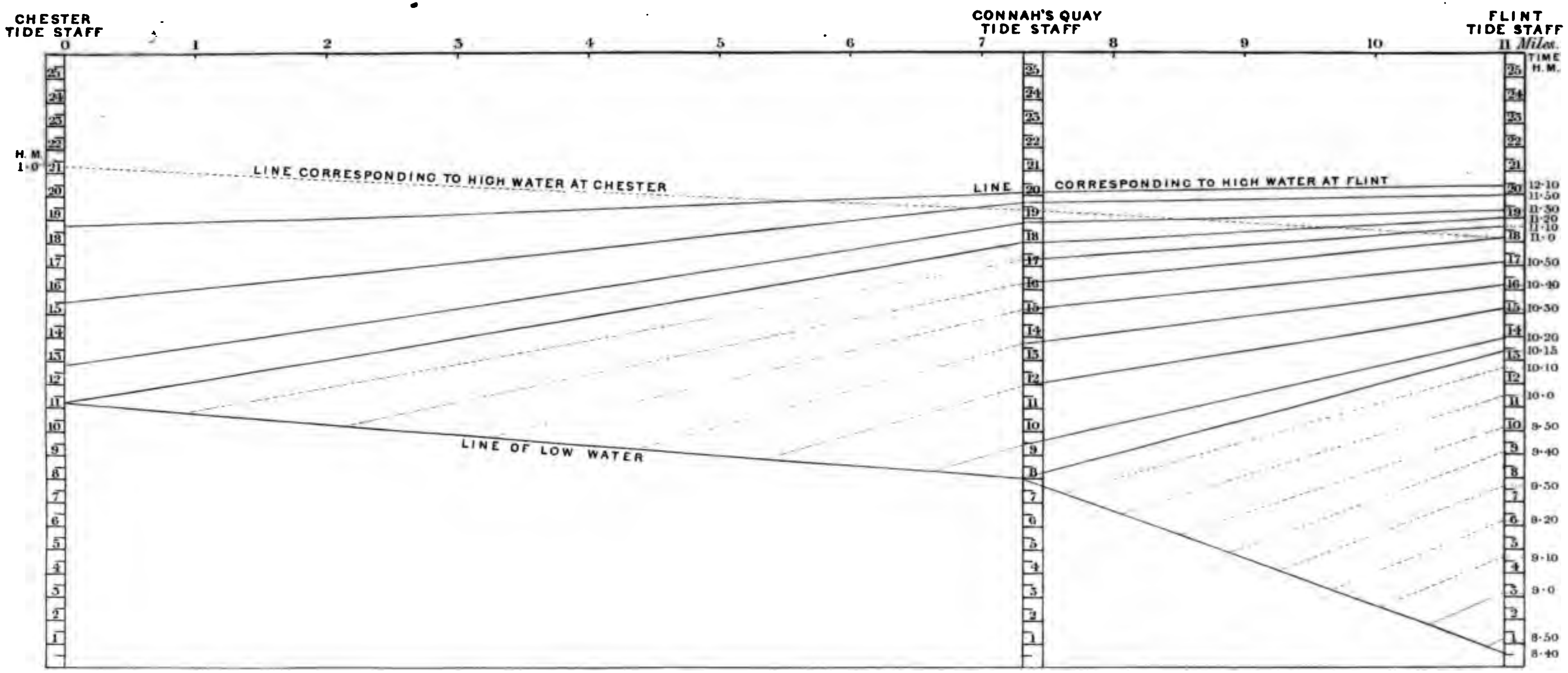
When the rise of tide, as indicated by the Liverpool tide table, is 18 feet on the Dock sill at Liverpool, the rise in the Dee is 20 feet 10 inches at Flint, 13 feet 8 inches at Connah's Quay, and 11 feet 5 inches at Chester.

Plates III. and IV. represent approximately the forms

RIVER DEE.

FLOOD OF A SPRING TIDE.

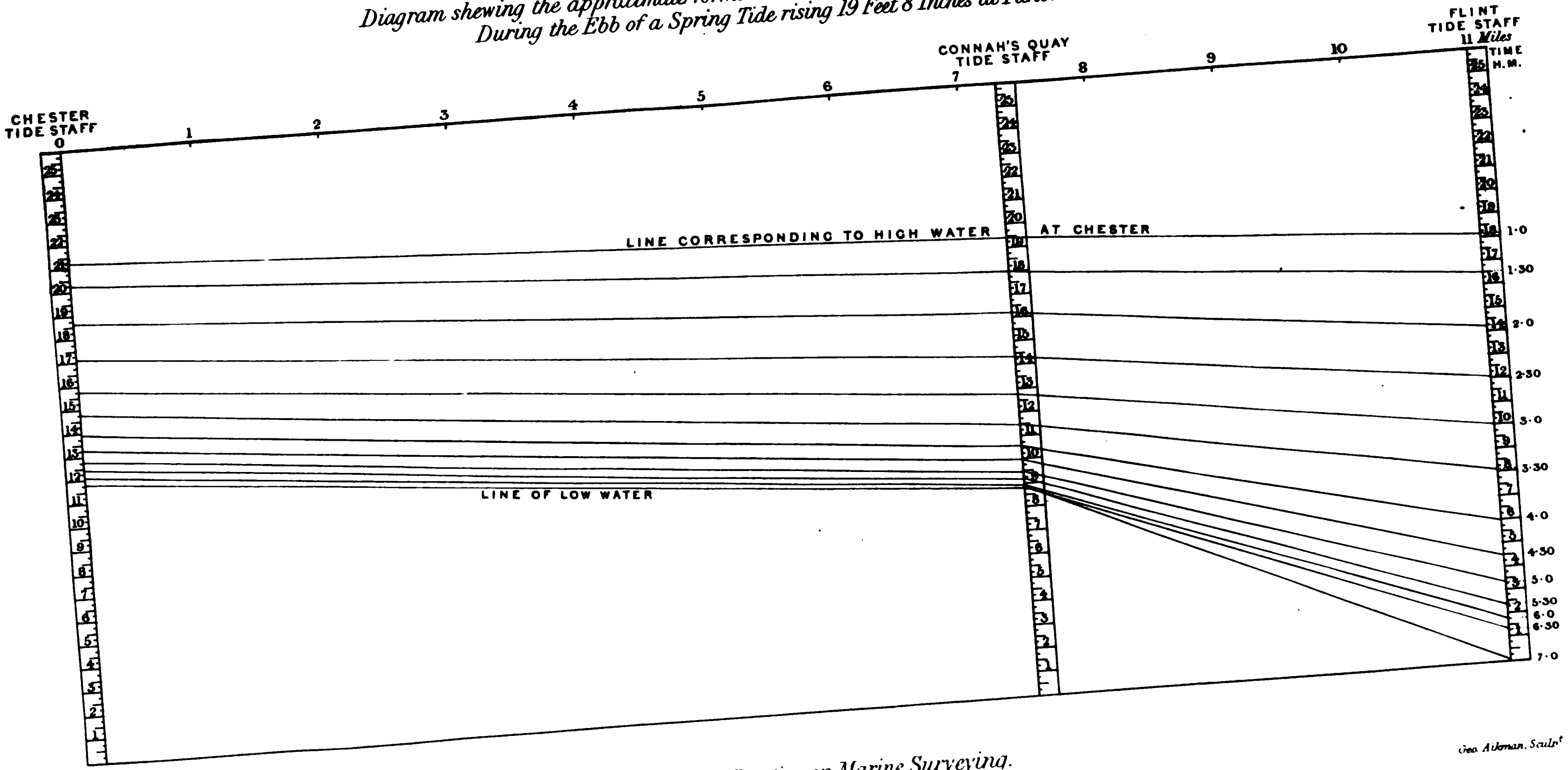
Diagram shewing the approximate forms assumed by the Tidal lines of the River Dee, During the Flood of a Spring Tide rising 19 Feet 8 Inches at Flint.



James Andrews, Del.t Geo. Aikman, Sculp.t

EBB OF A SPRING TIDE.

Diagram shewing the approximate forms assumed by the Tidal lines of the River Dee, During the Ebb of a Spring Tide rising 19 Feet 8 Inches at Flint.



Geo. Aikman, Sculpt

Stevenson's Treatise on Marine Surveying.

James Andrews, Delt

assumed by the tidal lines of the river, to which the attention of the reader is particularly directed. It is much to be regretted that in this case, as well as in the generality of surveys for engineering purposes, a greater range of tide-observations could not be obtained, and a nearer approach to their actual form could not be made, for the reasons stated in page 38. Plate III. represents the flood lines of a tide rising 19 feet 8 inches at Flint. In this, as well as in the other diagrams illustrative of the rise or fall of the tides, the perpendicular lines shew the relative positions of the stations, and are graduated in the same way as the tide gauges. On the horizontal line at the top of the diagrams, the relative distances between the stations are marked in miles, and at the right side of the plates, the time corresponding to the level of the tide is expressed in hours and minutes. The hard diverging lines are drawn through the points at which the tide stood at the different stations, as ascertained by observation, and represent the tidal lines of the river. Those which are *dotted* shew the probable direction of those lines, when their forms could not, for want of additional data, be more accurately determined.

The tide, as will appear from an inspection of Plate III., began to rise at Flint at 8 hours 40 minutes; at 10 hours 15 minutes it had risen 12 feet 8 inches, and at that time had just appeared at Connah's Quay, the surface of the water at Flint being 5 feet 4 inches above that at Connah's Quay. At 11 hours 20 minutes the tide had risen 18 feet 4 inches at Flint, and was 1 foot above the level of the water at Connah's Quay, and 7 feet 10 inches above that at Chester, at which place the tide had just begun to appear. Thus,

while at low water there is a fall of 11 feet from Chester to Flint, there was at the time above mentioned a fall of no less than 7 feet 10 inches on the surface of the water from Flint to Chester. At 12 hours 10 minutes it was high-water at Flint, and at that time there was a fall of 1 foot 7 inches to Chester; but the high water at Chester did not occur till one o'clock, by which time the water at Flint had fallen 2 feet 2 inches, and the fall on the surface of the water from Chester to Flint was 3 feet 1 inch. On referring to plate IV., which shews the lines of ebb tide on the same day, it will be found that the water subsides gradually, and that the tidal lines approach much more nearly to parallelism and horizontality than during flood tide. The upper line of this diagram corresponds with the tidal line when it is high water at Chester.

A similar series of facts obtained in surveying the River Lune in Lancashire, in reference to the improvement of its navigation, will be found to corroborate the general results deducible from those made at the Dee, although the two cases are very different, as regards both the extent of the surveys and the configuration of the countries in which they were made.

The observations at the Lune were taken during the months of August and September 1838 at three parts of the river, namely, Glasson Dock, Heaton Point, and Lancaster Quays. The distance from Glasson to Heaton is 3¼ miles, and that from Heaton to Lancaster 2¼ miles, making the whole distance from Glasson to Lancaster 5½ miles.

The high water line at Glasson, Heaton, and Lancaster, was found occasionally to stand exactly at the same height;

but the average difference of level gave a fall of 1 inch from Glasson to Heaton, and a rise of 3 inches from Heaton to Lancaster, the surface of the water at Heaton being slightly depressed, and a small degree of concavity on the high water line observable. The occurrence of this irregularity may be accounted for by the configuration of the estuary of the river, which is shewn in the chart of the Lune appended to this treatise. A great contraction of the space between the banks occurs at Glasson, which checks the free flow of the tidal wave, and consequently raises its level at that place. After passing this contraction, however, the water flows into the large tidal basin or area in which the Heaton tide gauge was placed, extending from Glasson towards Lancaster, and here the tide level again falls, owing to the much larger surface over which the water is distributed.

The time of high water was found, on eight occasions out of twenty four, to be exactly the same at Glasson, Heaton, and Lancaster. The difference of time, however, between Glasson and Lancaster varied from 0 to 10 minutes, and the average of the observations gave the time of high water at Glasson $3\frac{3}{4}$ minutes earlier than at Lancaster; but this difference in time seemed to depend entirely on the wind or state of the weather, and not on the circumstance of the tide being spring or neap.

The average level of the low water at Glasson is 7 feet 3 inches below that at Heaton, giving, in a distance of $3\frac{1}{4}$ miles, an average fall of 26.76 inches per mile; and the average level of the low water at Heaton is 3 feet 9 inches below that at Lancaster, giving, on the distance of $2\frac{1}{4}$ miles, an average fall of 20 inches per mile. The level of the low

water at Glasson is, therefore, 11 feet below that at Lancaster, giving, on the whole distance of $5\frac{1}{2}$ miles, a fall on the low water line of 24 inches per mile between the two places.

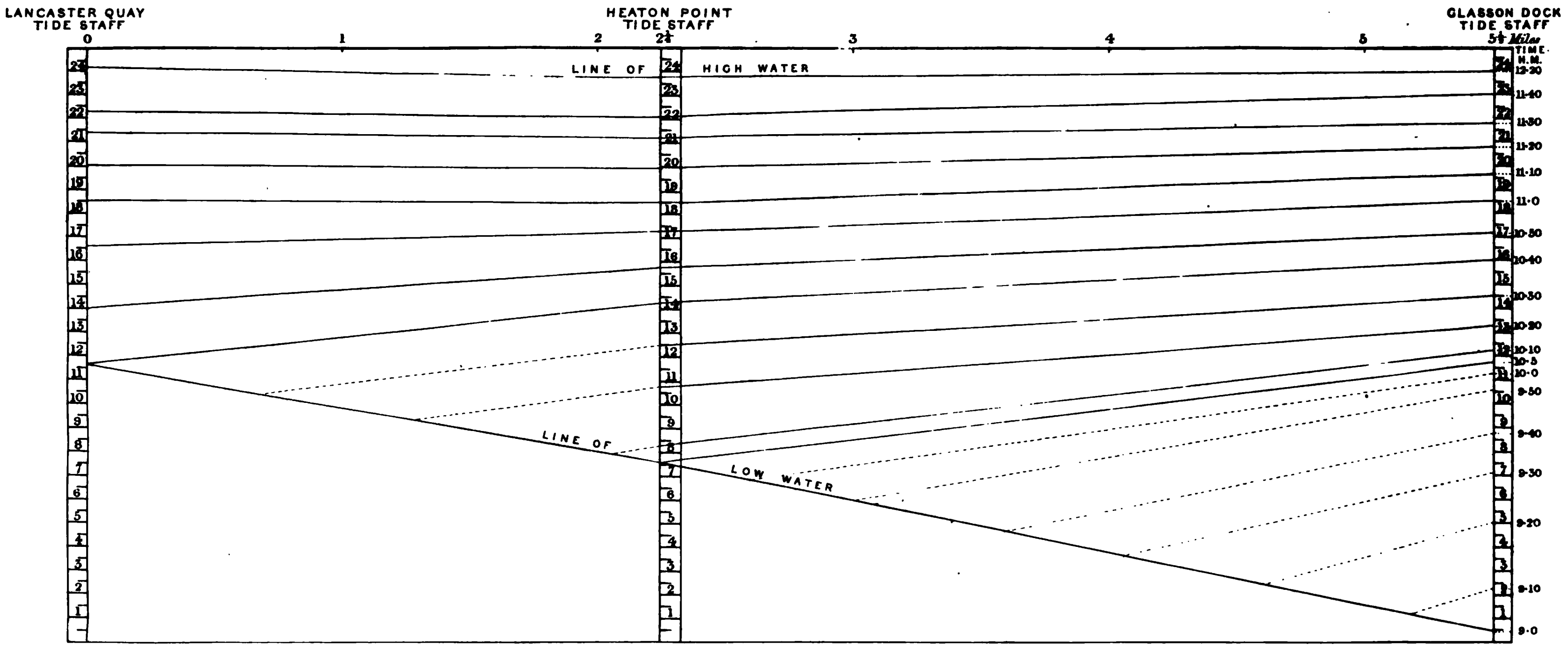
When the rise of tide, as indicated by the Liverpool tide table, is 18 feet above the dock sill, the rise of tide in the Lune is 21 feet 1 inch at Glasson, 13 feet 10 inches at Heaton, and 10 feet 2 inches at Lancaster.

Plates V. and VI. represent the forms assumed by the tidal lines of the Lune during a spring tide which rose 23 feet 4 inches at Glasson. The tide, as will appear from an inspection of Plate V., began to rise at Glasson at 9 hours; at 10 hours 5 minutes it had risen 11 feet 4 inches, and at that time had just appeared at Heaton; the surface of the water at Glasson being 4 feet 3 inches above that at Heaton. At 10 hours 40 minutes the tide had risen 15 feet 6 inches at Glasson, and was 1 feet 9 inches above the level of the water at Heaton, and 4 feet 4 inches above that at Lancaster, at which place the tide had just begun to appear. Thus, while at low water there is a fall of 11 feet from Lancaster to Glasson, there was at the time mentioned a fall of 4 feet 4 inches on the surface of the water from Glasson to Lancaster. At 12 hours 20 minutes it was high water at Glasson, Heaton, and Lancaster, and at that time there was a fall of a few inches both from Lancaster and from Glasson to the intermediate station at Heaton, producing the concavity of the high water line already alluded to.

On referring to Plate VI. which shews the lines of ebb tide on the same day, it will be found that the water subsides gradually, a slight degree of concavity on the surface

FLOOD OF A SPRING TIDE.

Diagram shewing the approximate forms assumed by the Tidal lines of the River Lune,
During the Flood of a Spring Tide rising 23 Feet 4 Inches at Glasson.



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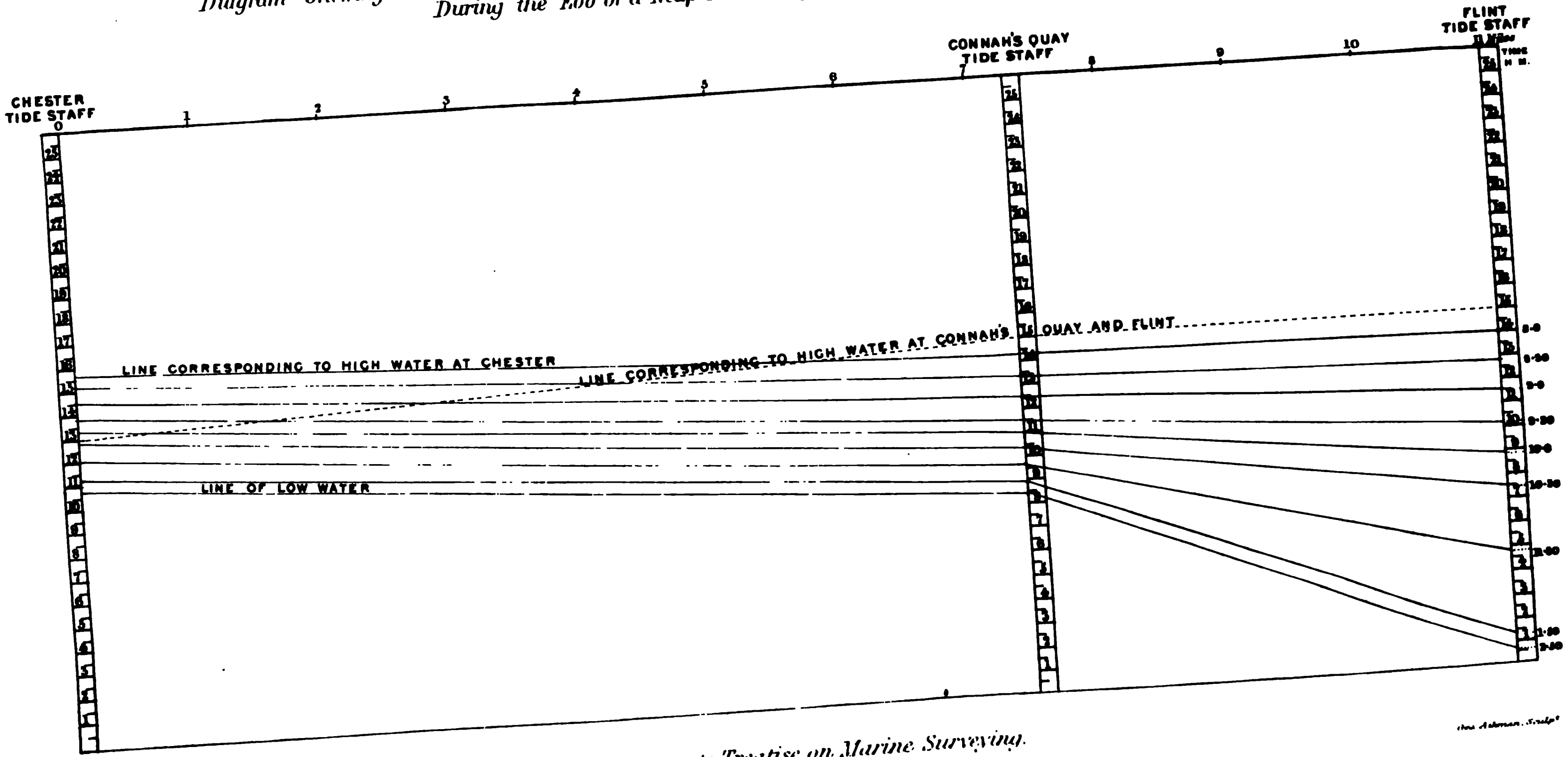
RIVER DEE.
EBB OF A NEAP TIDE.

Diagram Shewing the approximate forms assumed by the Tidal lines of the River Dee on the 22^d May 1839 During the Ebb of a Neap Tide rising 4 Feet 11 Inches at Chester.



Stevenson's Treatise on Marine Surveying.

while at low water there is a fall of 11 feet from Chester to Flint, there was at the time above mentioned a fall of no less than 7 feet 10 inches on the surface of the water from Flint to Chester. At 12 hours 10 minutes it was high-water at Flint, and at that time there was a fall of 1 foot 7 inches to Chester; but the high water at Chester did not occur till one o'clock, by which time the water at Flint had fallen 2 feet 2 inches, and the fall on the surface of the water from Chester to Flint was 3 feet 1 inch. On referring to plate IV., which shews the lines of ebb tide on the same day, it will be found that the water subsides gradually, and that the tidal lines approach much more nearly to parallelism and horizontality than during flood tide. The upper line of this diagram corresponds with the tidal line when it is high water at Chester.

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The high water line at Glasson, Heaton, and Lancaster, was found occasionally to stand exactly at the same height;

but the average difference of level gave a fall of 1 inch from Glasson to Heaton, and a rise of 3 inches from Heaton to Lancaster, the surface of the water at Heaton being slightly depressed, and a small degree of concavity on the high water line observable. The occurrence of this irregularity may be accounted for by the configuration of the estuary of the river, which is shewn in the chart of the Lune appended to this treatise. A great contraction of the space between the banks occurs at Glasson, which checks the free flow of the tidal wave, and consequently raises its level at that place. After passing this contraction, however, the water flows into the large tidal basin or area in which the Heaton tide gauge was placed, extending from Glasson towards Lancaster, and here the tide level again falls, owing to the much larger surface over which the water is distributed.

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water at Glasson is, therefore, 11 feet below that at Lancaster, giving, on the whole distance of $5\frac{1}{2}$ miles, a fall on the low water line of 24 inches per mile between the two places.

When the rise of tide, as indicated by the Liverpool tide table, is 18 feet above the dock sill, the rise of tide in the Lune is 21 feet 1 inch at Glasson, 13 feet 10 inches at Heaton, and 10 feet 2 inches at Lancaster.

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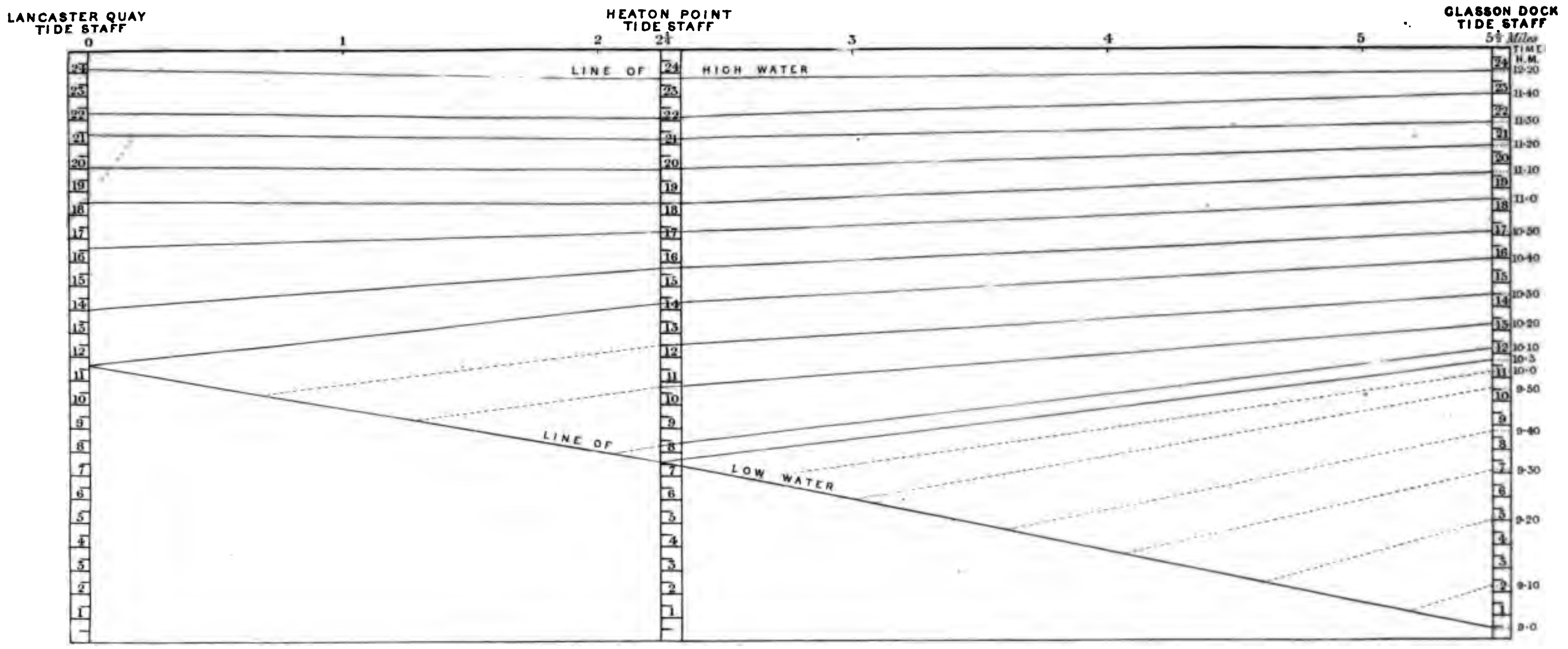
On referring to Plate VI. which shews the lines of ebb tide on the same day, it will be found that the water subsides gradually, a slight degree of concavity on the surface



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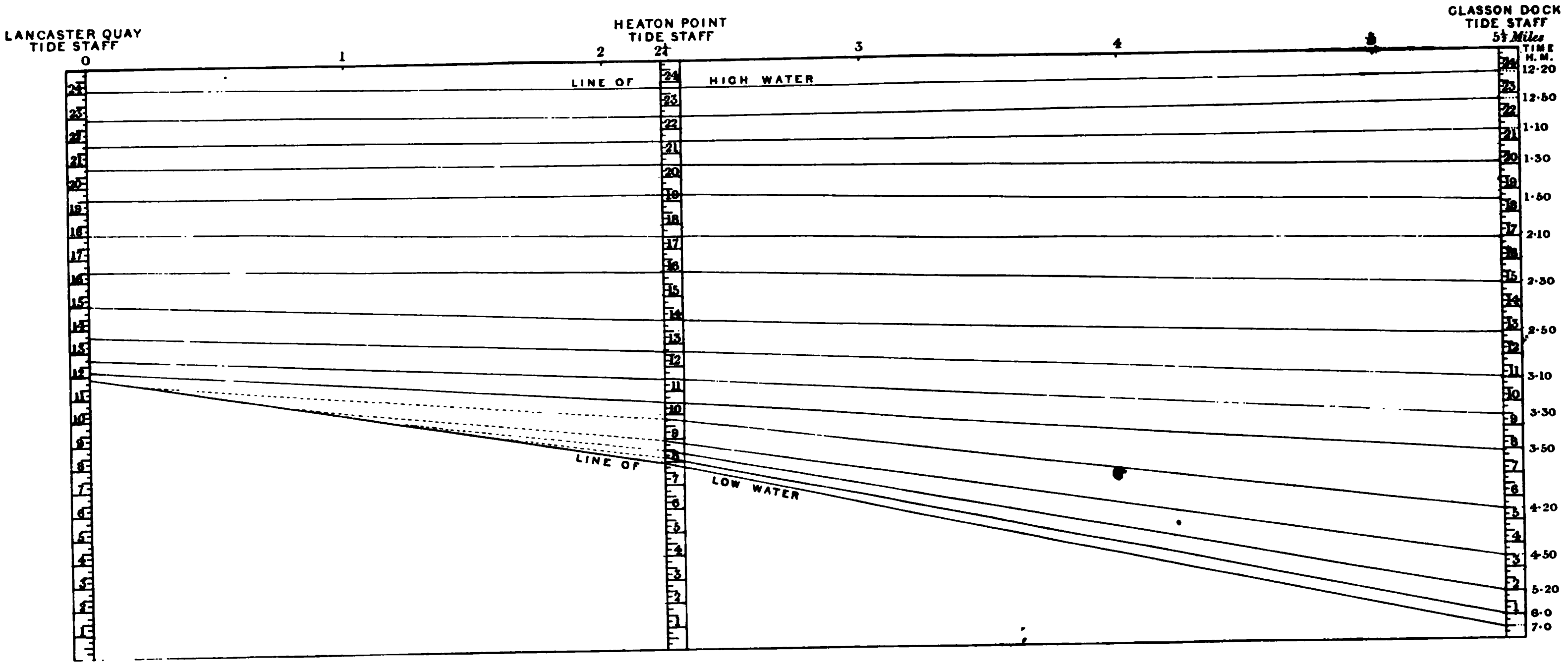

Stevenson's Treatise on Marine Surveying.

Geo. Aikman, Sculpt

James Andrews, Delt

RIVER DEE.
EBB OF A NEAP TIDE.

Diagram Shewing the approximate forms assumed by the Tidal lines of the River Dee on the 22d May 1839 During the Ebb of a Neap Tide rising 4 Feet 11 Inches at Chester.

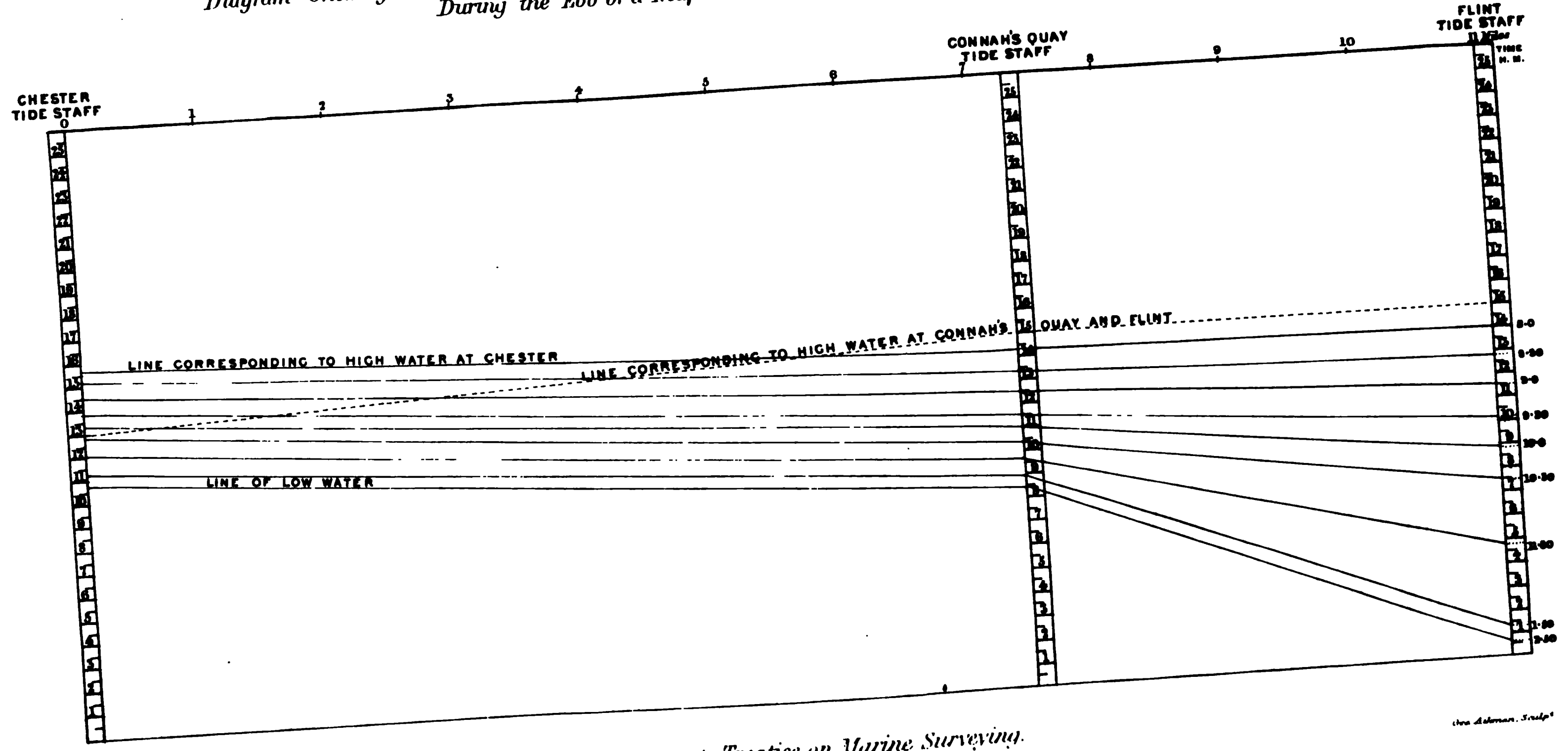

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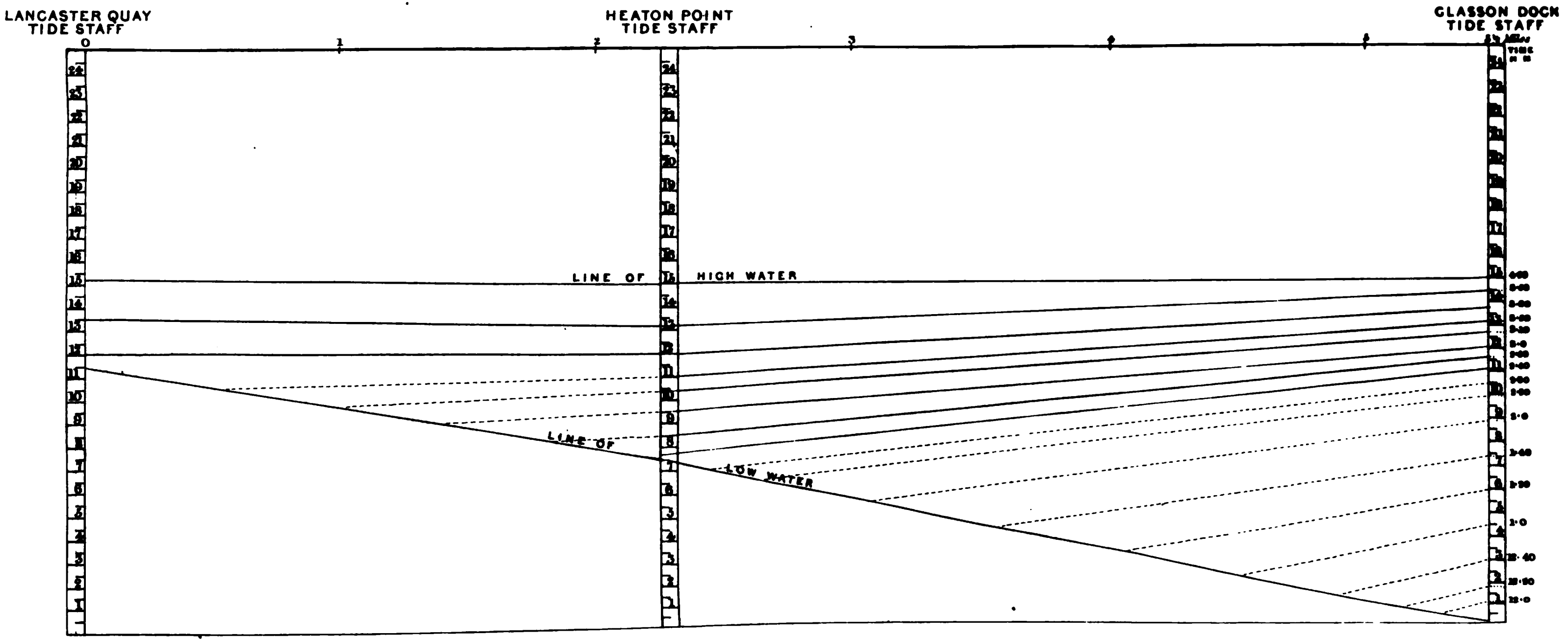
PLATE VII.

RIVER LUNE.

FLOOD OF A NEAP TIDE.

Diagram shewing the approximate forms assumed by the Tidal lines of the River Lune, During the Flood of a Neap Tide rising 14 Feet 10 Inches at Glasson.



Stevenson's Treatise on Marine Surveying.

Geo. Aikman Sculp.

being discernible for an hour and a half after high water; and during the whole of the ebb tide, as in the former case, the lines approach much more nearly to parallelism and horizontality than during flood tide. The upper tidal line of this diagram corresponds with that of high water.

I have found in all rivers whose tides I have examined with this object in view, that, on comparing the lines formed during spring with those formed during neap tides, the latter are invariably more nearly parallel to the line of high water; the deviation from parallelism decreasing in proportion to the decrease in the rise of tide. For the purpose of illustrating this, I have given, in Plates VII. and VIII., an example of the lines formed by the flood of a neap tide on the Lune, and the ebb of a neap tide on the Dee, which, when compared with the examples of the spring tides of these rivers already given, will be found to approach much more nearly to horizontality and parallelism. A farther illustration of this is presented in the following tabular views of the maximum difference of level between the surface of the water at Flint and Chester on the Dee, and at Glasson and Lancaster on the Lune, during the flow of tides of various amounts of vertical rise.

RIVER DEE.

Date.		Rise of Tide at Flint.		Maximum Fall from Flint to Chester.	
1839.		Feet.	In.	Feet.	In.
May	21.	14	0	3	8
...	23.	15	6	4	5
...	25.	16	4	5	8
...	29.	18	0	6	6
June	10.	19	8	7	10

RIVER LUNE.

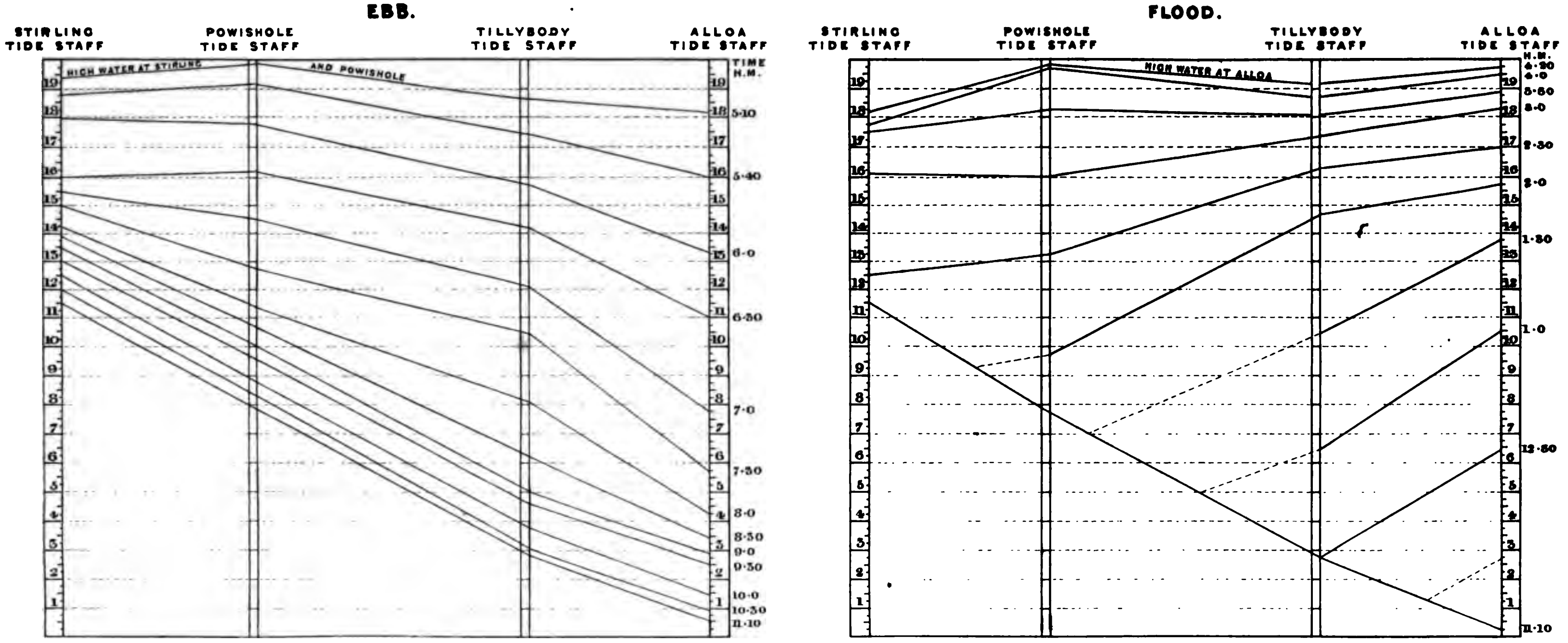
DATE.	Rise of Tide at GLASSON.		Maximum Fall from GLASSON to LANCASTER.	
1839.	Feet.	In.	Feet.	In.
Aug. 29.	12	1	1	1
... 31.	12	9	1	6
Sept. 1.	15	4	2	0
... 3.	19	8	2	10
... 5.	23	2	3	2
... 6.	23	6	4	4

I shall only refer to another example which is chiefly interesting, as shewing the undulating lines of the tide wave in its passage up the narrow channel of a winding river. I allude to the Forth in Stirlingshire, in which, from its tortuous course, the tides are somewhat remarkable. To give an idea of the windings of this river, it may be stated that the distance in a straight line between the towns of Alloa and Stirling, both of which are situated on its banks, is 5 miles; while that by the river's course is no less than 10½ miles. The tides, however, in the Forth, are not so rapid as those to which I have been referring, otherwise the deviations in the tidal lines would doubtless have been much greater than they were found in reality to be.

The tide observations on this river were made under the direction of my father in the year 1825, and from the winding nature of the stream, it was found necessary to have four stations, namely, at Alloa, Tillibody, Powisholé, and Stirling. The deviation in the lines will be seen by reference to the diagrams in Plate IX., which are constructed nearly

RIVER FORTH.

Diagram shewing the approximate forms assumed by the Tidal lines of the River Forth.



Stevenson's Treatise on Marine Surveying.

James Andrews Del.t

Geo. Aikman Sculp.t

in the same manner as those already described, and represent the forms assumed by the surface of the water during flood and ebb, at the end of every successive half hour. The most anomalous result of this investigation occurs at Powishole, where the undulating surface of the water was found to rise higher than at any other point on the river, either above or below it.

Although many other series of observations affording similar results might be given, it seems unnecessary to enter upon them; my only object being to enable the reader to form distinct ideas as to the nature of the deviations in the tidal lines, and the several investigations that require to be instituted in making a correct survey. The examples I have given, it is presumed, afford sufficient information for that purpose. I shall, therefore, proceed to shew in what manner and to what extent the accuracy of the soundings may be affected by the nonparallelism of the tidal lines to the line of high water; and, that the observations to be made may be clearly understood, I shall, in the first place, offer a few remarks on the datum to which the soundings should be reduced, and also on the nature and use of the reference which is made to the tide gauges, in the reduction of their depths to that datum.

It is evident that all soundings must be reduced or referred to one datum line, before a correct notion can be formed of the depths of water at the places where they were taken. Different opinions have been advanced as to the most convenient datum to be used for this purpose. When the whole rise of the tide can be observed, which is the case in harbour surveys situated on the coast, the "half tide

mark," or that central point from which the high and low water levels of every tide are very nearly equidistant, is a convenient point for referring to. The existence of such a point "equidistant from the high and low water of any one tide and on the same level, or coinciding with, the points half way between high and low water of every other tide," has been determined by observations made in several situations. It is believed to have been first detected in 1830 by my father while surveying the Dornoch Frith in reference to a salmon fishing question, and is particularly alluded to in his report to the Court of Session on that subject, dated 31st January 1831. In 1833 it was found to exist in the Frith of Forth in making the tide observations for a harbour survey; and in 1834, in surveying the Skerryvore Rocks on the west coast of Scotland, with a view to the erection of the Skerryvore Lighthouse. In 1835, I obtained the same results at the Isle of Man; and in the same year Captain Denham brought a similar result, obtained from extensive observations made at Liverpool, before the meeting of the British Association held at Dublin. The agreement of these different series of observations made at points so far distant from each other seems to prove the universality of the phenomenon, at least on the shores of this country.

It is evident, however, that this datum is only applicable to situations where the whole rise of tide can be observed, which, in river surveys, is rarely the case, even at a single station, the bottom of the gauges, owing to the rise on the bed of the river, being generally above the low water line of the ocean. The datum line assumed in such surveys is therefore that

of high water of an ordinary spring tide. This, however, is an indefinite datum, unless the rise of that which has been assumed as the ordinary spring tide be distinctly specified, in which case it is quite explicit, and is found perfectly to answer the object intended; for if we are told that the soundings on any river are reduced to high water of an ordinary spring tide, rising 16, 18, or 20 feet, as the case may be, at a certain point in the river which must be mentioned, then the depths in reference to the high water of any other tide can, with this information, be easily ascertained.

In order to explain the use of the reference which is made to the tide gauges, in reducing the soundings, we shall suppose that a depth was taken in the middle of an estuary, and that the observer, at the time he made the observation, had not any means of ascertaining the state of the tide. Such an observation would evidently be of no practical use, from the circumstance of its being impossible to ascertain whether the tide had still to rise, had attained its full height, or had fallen a certain number of feet at the moment it was made, without a distinct and accurate knowledge of which, the depth could not be reduced to the level of the high water of any particular tide. If all the depths were taken exactly at the time of high water of the tide to which they were to be referred, they would not require any correction; but it is obvious that in practice this could not be done; and recourse is consequently had to the tide observations, by means of which the reduction is easily effected. All that is necessary for this purpose, is to note the time at which the sounding is taken, in order that the height of the tide at the nearest gauge corresponding to that time may be afterwards as-

certained. The method of obtaining the correcteu ~~, resolves itself into one of three cases, depending on the time of tide at which the observation was made. It is as follows:—

Let α represent the depth of sounding made at a certain hour.

β the height at which the water stood on the tide gauge at the same hour.

γ the height to which high water of ordinary spring tides rises on the gauge,—which will be ascertained while the survey is in progress by the series of tide observations made in the manner already explained; and

δ the depth of the sounding reduced to high water.

Now, in the first case, if β is below the level of γ, then

$$\delta = \alpha + (\gamma - \beta).$$

In the second case, if β is on the same level as γ, then

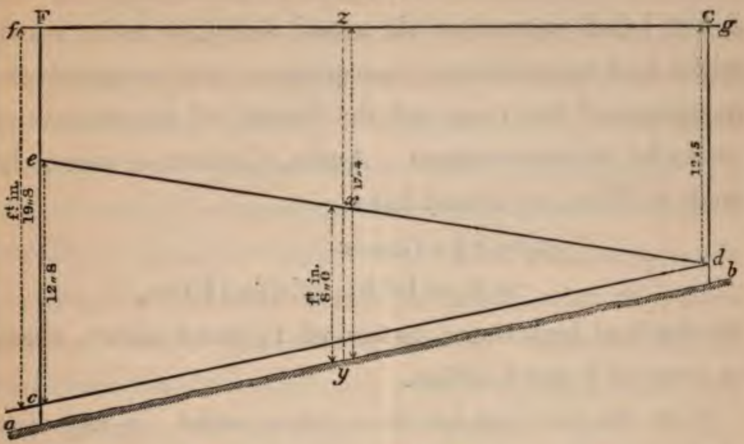
$$\delta = \alpha;$$

And in the third case, which may happen in a high spring or equinoctial tide, if β is above the level of γ, then

$$\delta = \alpha - (\beta - \gamma).$$

These formulæ would give the true corrections of the soundings, however far removed from the tide gauge their positions might be, if the lines formed by the tidal wave were parallel to that of high water at all times of tide, as in that case the vertical spaces $\gamma-\beta$ or $\beta-\gamma$, intercepted between the high water line, and the other tidal lines, would be equal throughout the whole of the tidal area of the river or estuary. But it has been shewn that the tidal lines are not parallel, and the formulæ I have given may therefore, under certain circumstances, lead to error. As an example of this, I shall take one of the tide lines of the Dee from

FIG. 4.



Let F and C, fig. 4., represent the positions of Flint and Connah's Quay tide gauges, and the intermediate point z the place at which the sounding was taken. Let F C represent the line of high water to which it is wished to reduce the sounding, $a\ b$ the bed of the river, $c\ d$ the low water line, and $e\ d$ the tidal line which existed when the observation was made, which is not imaginary, but will be found to correspond with that at 10 hours 15 minutes, as represented in Plate III. Further, let the sounding $x\ y = 8$ feet. Let the depth at high water $z\ y$ at the position of the sounding, as measured on the diagram, = 17 feet 4 inches. Let the rise of tide at Connah's Quay $g\ d$ = 12 feet 5 inches, the rise of tide at Flint $c\ f$ = 19 feet 8 inches, and the height at which the water had risen on the Flint gauge, when the sounding was made, $e\ c$ = 12 feet 8 inches. Now, suppose the sounding is to be reduced by a reference to Connah's Quay; according to the foregoing formula we should have

$$z\,y = x\,y + (g\,d - 0)$$
$$= 8^{f} + (12^{f}.5 - 0 = 20 \text{ feet 5 inches},$$

the depth at high water, instead of 17 feet 4 inches, giving 3 feet 1 inch more than the actual depth, an error which might lead to unpleasant consequences, both as regards the navigation of the river and the framing of an estimate of works for its improvement. Again, if reference were to be made to Flint, we should have

$$zy = xy + fc - ec$$
$$= 8^f. + (19^f.8 - 12^f.8) = 15 \text{ feet},$$

the depth at high water, instead of 17 feet 4 inches, being an error of 2 feet 4 inches.

Now, the case that has been taken, which, in any view of the subject, would involve an error in the depth, either of 3 feet 1 inch, or 2 feet 4 inches, is not the worst that may be cited, for, under certain circumstances, and in certain situations, the error would be considerably greater.

Nor, indeed, are the high water depths the only results that would be affected. The section of the bed of the river, the depths of the soundings when reduced to low water, and the heights of the sand banks above the low water line, the correctness of which, as will be explained in Chap. X., depend entirely on the accuracy of the high water depths, would all be equally erroneous. It is obviously of great importance, therefore, that the engineer should not only be fully aware of the cause of these errors, and the extent to which the results of a survey may be affected by them, but also that he should know, and be able to apply where necessary, the means by which they may be neutralized.

It has been shewn that the erroneous results alluded to arise from the nonparallelism of the tidal lines to the line of the high water to which the soundings are to be reduced, and it has been stated that the most effectual means of avoiding

inaccuracy, from this cause, is to increase the number of gauges; but even this precaution, unless carried to an extent which may, in ordinary practice, be safely regarded as quite unattainable, would not produce the desired effect. The only really practicable cure which can be applied, is that of taking the soundings when the lines are most nearly parallel to the line of high water. That there are not only certain tides, but also certain periods of every tide, when this approach to parallelism is much more near, than at other times, has, it is presumed, been clearly established; and in accordance with this view of the subject, I shall give five rules for direction, in making the soundings, the correctness of which I have had repeated opportunities of practically testing.

First, Soundings made in the immediate vicinity of the gauge, by a reference to which they are to be corrected, are not appreciably affected by deviations from parallelism, and may be taken at any time of tide, and under any circumstances.

Second, The farther distant the positions of the soundings are from the gauge, by a reference to which they are to be corrected, the greater is the chance and the amount of error which may arise from nonparallelism.

Third, Soundings should be made during neap in preference to spring tides.*

Fourth, Soundings should be made in ebb in preference to flood tides.

* The strong currents, during spring tides, are unfavourable for the purpose of sounding, independently of the greater deviation from parallelism in the lines.

Fifth, Soundings to be taken in flood tides, especially during springs, should not be made till within about an hour of high water.

If these precautionary rules be kept in view, they will be found to counteract in so great a measure the effects of non-parallelism, as to insure, in most cases, sufficient accuracy for all practical purposes, in reducing the observations. They apply most particularly to rivers in which the rise of tide is great, and the currents are strong; but they may be said to be applicable, in a greater or less degree, to all situations. A compliance with them may, at first sight, appear to be difficult, and to entail great loss of time in making the marine department of the survey, but the object to be attained is very important, and well worthy of some sacrifice of time; and if calm weather must be chosen for making the triangulation and taking the levels of the tide gauges, there is no reason why favourable tides should not be chosen for taking the soundings. The rules I have given may, in fact, be embraced in these two directions, a compliance with which does not seem to involve any great difficulty: First, not to take soundings during very high tides; and secondly, to confine all the observations made (till within about an hour of high water,) to the immediate vicinity of the gauge by a reference to which they are to be corrected.

The methods of taking the soundings, and of making the observations for determining their positions, have still to be noticed before leaving this subject. It will be found convenient to employ a well fitted boat of moderate size for this purpose, manned by not fewer than three persons who understand its management; two of these are occupied in pull-

ing the boat, and the third in casting and taking up the anchor when necessary, and in making the soundings. A fourth person is required as an observer, to take the angles for ascertaining the positions of the soundings, and a fifth to steer the boat, and to register the angles, the depths and the times at which the soundings are taken.

It often happens, in questions regarding the improvement of the navigation of a river, or even for other purposes, that it is necessary to be able to determine its tidal capacity, or in other words, the number of tons or cubic yards of water which flow into it and again return to the ocean during every tide. In order to be able to calculate this approximately (for the result can only be an approximation), as well as to obtain an accurate idea of the depths of water in different parts of the estuary, the soundings should be equally distributed over the tidal area of the river, so as to give, when protracted, as correct a general view of the inequalities of the bottom as possible, as shewn in the chart of the Lune at the beginning of this volume. That this object may be satisfactorily attained, it is necessary to follow some system in making the observations of the depths; for if they are taken at random, without reference to any particular marks or lines of direction, it will, in all probability, be found, on protracting them, that large areas occur without a single sounding to indicate the depth of water, while in other places, in consequence of several lines of soundings crossing each other, owing to the want of proper arrangement, the observations are so numerous that it is impossible to protract the whole of them on the plan. The inexperienced are very apt to fall into this error when surveying a

broad estuary, having a great expanse of water, by which the eye is apt to be deceived, and it arises from the difficulty of being able to ascertain, without some definite marks for direction, the part which has, from that which has not been sounded. It will therefore be found useful, before proceeding to make the soundings, to fix upon the number required, and the directions in which they are to be taken, points in the determination of which the engineer must be guided partly by the nature of the inquiry in which he is engaged, and partly by the configuration of the bed and banks of the river. When these preliminary matters have been arranged, the soundings may be commenced, and ought to be taken in straight lines extending from shore to shore; the boat being steered as correctly as the currents will allow of, by keeping some well defined object on the water's edge in a line with another in the distance. That the soundings may occur at nearly equal intervals, they should be taken at every twenty or thirty strokes of the oar, or at any distance apart that may be considered best suited to the circumstances of the investigation.

It is sometimes found necessary, owing to the strength of the currents, especially in broad estuaries, when the soundings are taken at considerable intervals, to anchor the boat when each sounding is made, and to ascertain its position by sextant observations. It is generally sufficient, however, that the position of every fifth or sixth sounding only be fixed, the positions of the intermediate ones being determined by dividing the space intervening between the points fixed by observation into equal parts, according to the number of soundings made.

The most convenient and easily applied observations for determining the positions of the soundings, are those made with the sextant, by an observer in the boat, to three objects on the land whose positions are known. The station poles used in the triangulation, and the spires, chimneys, and other prominent objects, whose positions have been determined in the manner described in Chapter I., are to be employed as points of observation for this purpose. Two angles taken to three points are sufficient to determine the position of the sounding: there can be no check on the correctness of the observation however, without three angles taken to four objects; and it is well, on that account, to take at least three when convenient.

As it has been stated that *two* angles may be taken to *three* objects, or that *three* angles may be taken to *four* objects, it seems almost unnecessary to shew, that the three or the four objects selected must occur in succession. Thus, in the case of three objects being chosen, if z be the point of observation, and A, B, C the objects fixed on, the two angles observed must be A z B and B z C, and when four objects, A, B, C, D are chosen, z still being the point of observation, the three observed angles must be A z B, B z C, and C z D. The observed angles may range from 40° to 120°; but should not, if possible, fall below or exceed these limits, as angles which are much smaller or larger than those named are apt to give erroneous results when protracted. The manner in which the position of the sounding is ascertained in this way, will be explained hereafter in treating of the protraction.

Some surveyors determine the positions of soundings by means of two or more theodolites placed at known points on the shore, from which simultaneous observations are made, by observers stationed at each instrument, to a flag which is hoisted in the boat at the moment the sounding is made; but this method occupies a greater number of observers than that which I have been recommending, is more tedious, more liable to inaccuracy, and on a great scale is wholly impracticable, and would never be resorted to, from preference, by any who can use the sextant.

When the depth of water does not exceed 10 or 12 feet, the soundings will be most conveniently made with a light graduated rod; but when this depth is exceeded, it is difficult to use a rod of sufficient length to reach the bottom, and recourse is had to a sounding line graduated to feet, half feet, and quarters.

It is almost unnecessary to remark, that the observations ought to be carefully and systematically registered. I append to this chapter, at page 70, the form which I have been in the habit of using for registering the soundings, shewing two examples. The first refers to the cases in which the position of each sounding is fixed, and the second to those in which only occasional sextant observations are made, as just alluded to. The tables are printed in black and red figures, the former representing those of the printed form, the latter the observations entered in the field.

The register is divided into seven columns; the *first* contains the names of the stations to which angles were taken with the sextant; the *second*, the angles observed; the *third*, the time at which the soundings were made; and

the *fourth*, the depths. The *fifth* contains the heights, at the times of observation, at which the water stood on the tide gauge, by a reference to which the soundings are to be reduced to high water. These heights, which, in the examples given, are for Heaton station, are taken from the Tide Books. The *sixth* column contains the depths of the soundings, reduced to high water by the formulæ given for that purpose at page 58. These two last columns are not used in the field work, but are filled up at a future period, before the soundings come to be protracted. The *seventh* column is for remarks.

In making lines of soundings extending across a river in the manner described, it is of consequence that the depths should be taken at shorter intervals apart, in approaching near to and in crossing the low water channel, as the soundings in that part of the river are not only more useful than those on the banks, as giving the greatest navigable depth, but also because they afford data for making the longitudinal section of the river, and ascertaining the rise of tide at different points in its course, as will appear more particularly hereafter. In the narrower parts of the river, the soundings are made in cross lines also, but are generally more numerous; sextant observations to some well known points on the land being noted, to fix each extremity of the lines, and determine their exact positions.

Lines of soundings should also be taken on the sites of all proposed new channels or river walls. The most favourable weather and tides should be chosen for this operation, so as to insure the greatest possible accuracy, as sections and estimates of the proposed works are generally made from the data so obtained, when the more accurate

results of levelling cannot be procured, which is often the case in such situations as those referred to.

In addition to the soundings already mentioned, which must be made while there is tide in the river, it is necessary that a line should be taken at low water in the centre of the low water channel, throughout the whole extent of the survey, for the purpose of being enabled to determine the rise of tide at different parts of the river; by which means the soundings may be reduced to low water, and the heights of the sand banks above the low water line ascertained, in the manner to be explained in Chapter X. The most convenient way of making these soundings is to row gently down the stream in a boat, taking the depths at regular intervals, to be ascertained by counting the strokes of the oars. The time should also be regularly taken, as errors may arise from the river being swollen above its ordinary size by land floods, or by an imperceptible flow of tide; but if the time is known, any error arising from these causes can be corrected by reference to the register of the tide gauges.

The soundings ought to be registered in columns; and in situations where the banks of the river are contracted, and the channel narrow, the best method of marking the distances gone over in floating down the stream, is to note in the field book the names of any objects on the banks (whose positions are known), opposite to the soundings taken abreast of them, as in the following example, which is taken from a field book:—

Depths. Feet.	In.		Depths. Feet.	In.	
4	0		4	9	Time, 10h. 20m.
3	9	Off Windmill.	4	6	
3	9	Time, 10h. 10m.	4	6	Off Redbank Station.
3	9		4	6	
4	3		4	7	
4	6		4	8	
4	10		4	7	
5	0		4	7	
4	6	Off Ferryhouse.	4	4	
4	3		4	4	
4	8		4	0	
4	8		4	3	Time, 10h. 30m.
4	8		4	8	
4	9				

When the river becomes broad, however, this method cannot be pursued, and the boat must in that case be brought to an anchor at proper intervals, and its position determined by sextant angles, in the manner already described, and the soundings registered, as shewn in example No. 2 of the sounding book.

(No. I.)

SOUNDINGS TAKEN AT THE RIVER LUNE 17th September 1838.

Stations.	Angles.		Time.		Depths.		Heights of Tide at Heaton Tide Gauge.		Reduced Depths.		Remarks.
	Deg.	Min.	H.	M.	Ft.	In.	Ft.	In.	Ft.	In.	Datum high water 3 ft. 9 in. on Heaton gauge.
Coleway Station and Heaton Station,...	121	0									Close to side of Coleway Marsh, Aldcliff Station, and St Mary's, in a line.
Heaton S. and Aldcliff S.	94	38	10	10	6	10	6	11	10	0	
Aldcliff S. and Redbank S.	56	48									
Coleway S. and Heaton S.	107	48									
Heaton S. and Aldcliff S.	100	32	10	15	8	1	6	9	11	1	Hard bottom.
Aldcliff S. and Redbank S.	60	31									
Coleway S. and Heaton North S.	106	2									
Heaton North S. and Aldcliff S.	95	55	10	20	8	3	6	8	11	2	Hard bottom.
Aldcliff S. and Redbank S.	66	16									
Coleway S. and Heaton N. S.	94	11									
Heaton N. S. and Marsh Lane S.	41	43	10	25	12	9	6	8	15	8	Hard bottom.
Marsh Lane S. and Aldcliff S.	56	33									
Coleway S. and Heaton South S.	69	44									
Heaton South S. and Aldcliff S.	115	31	10	29	11	4	6	7	14	2	Sand.
Aldcliff S. and Redbank S.	83	53									

STATIONS.	ANGLES.		TIME.		DEPTHS.		HEIGHTS OF TIDE AT HEATON TIDE GAUGE.		REDUCED DEPTHS.		REMARKS.
	Deg.	Min.	H.	M.	Ft.	In.	Ft.	In.	Ft.	In.	
Coleway Station and Heaton Station....	63	43									
Heaton S. and Aldcliff S.	84	45	10	50	4	9	7	2	8	2	Datum high water [illegible] ft. 9 in. on Heaton gauge.
Aldcliff S. and Stile S.	45	13			3	6			6	11	
					3	5			6	11	
					3	4	7	3	6	10	
					3	4			6	10	
					3	4			6	11	
					3	3	7	4	6	10	
					3	3			6	10	
					3	3			6	11	
					3	3	7	5	6	11	
					3	5			7	1	
Redbank S. and Coleway S.	69	51			3	6			7	3	
Coleway S. and Heaton S.	61	20	11	0	3	9	7	6	7	6	
Heaton S. and Aldcliff S.	77	17			5	11			9	8	
					6	6			10	3	
					6	5			10	2	
					4	9			8	6	
					3	0			6	9	

CHAPTER V.

LOW WATER SURVEY.

Objects of the low water survey—Difficulties encountered in making it—Surveys situated on the coast and in rivers—Use made of the triangulation stations—Observations for fixing positions of points in survey—Changes on sand banks produced by spring tides, high winds, &c.—Different methods of keeping field book—Examples—Method of executing the field work—Dangers to be avoided in making low water survey—Means for averting them—Dangers in consequence of anomalous flow of tides—Example of this on the Dee—Cause of the phenomenon.

THE low water survey of the tidal area of the river is the operation to be explained in the present chapter. The points to be determined in this important department are the direction of the low water channels, the outlines of the banks of sand or gravel which form the bed of the estuary, and the positions of all rocks, shoals, or other obstructions to navigation; and although the case of a river survey has been taken for the sake of illustrating the method to be pursued, it is to be understood, as explained in the Preface, that the following remarks apply with equal propriety to any marine survey made for engineering purposes.

When the estuary to be surveyed is broad, and the river, as often happens, is divided into two or three low water channels, and seeks its way to the sea by numerous windings among extensive sand banks intersected in all directions by sleeves of water, the delineation of the low water lines is often attended with much trouble, if not with danger, and even in the most favourable situations it will generally be found that the satisfactory execution of this department is the most difficult part of the survey.

This difficulty may be attributed to two causes; the flatness of the surface to be surveyed, which prevents a full view of the windings of the river from being obtained, and the shortness of the time that can be devoted to it on any one day, which, from the nature of the investigation, is necessarily limited to the duration of low water. Advantage should therefore be taken of every means by which its execution may be facilitated; and, for this purpose, if there be any high ground on the shore of the estuary, the river should be viewed from it during low water, and a sketch from such a point of view made either by the hand, or with the camera lucida, or any other suitable instrument, will, in many cases, be found a great assistance in enabling the surveyor to trace the windings of the channel, when otherwise he would be involved in doubt and difficulty.

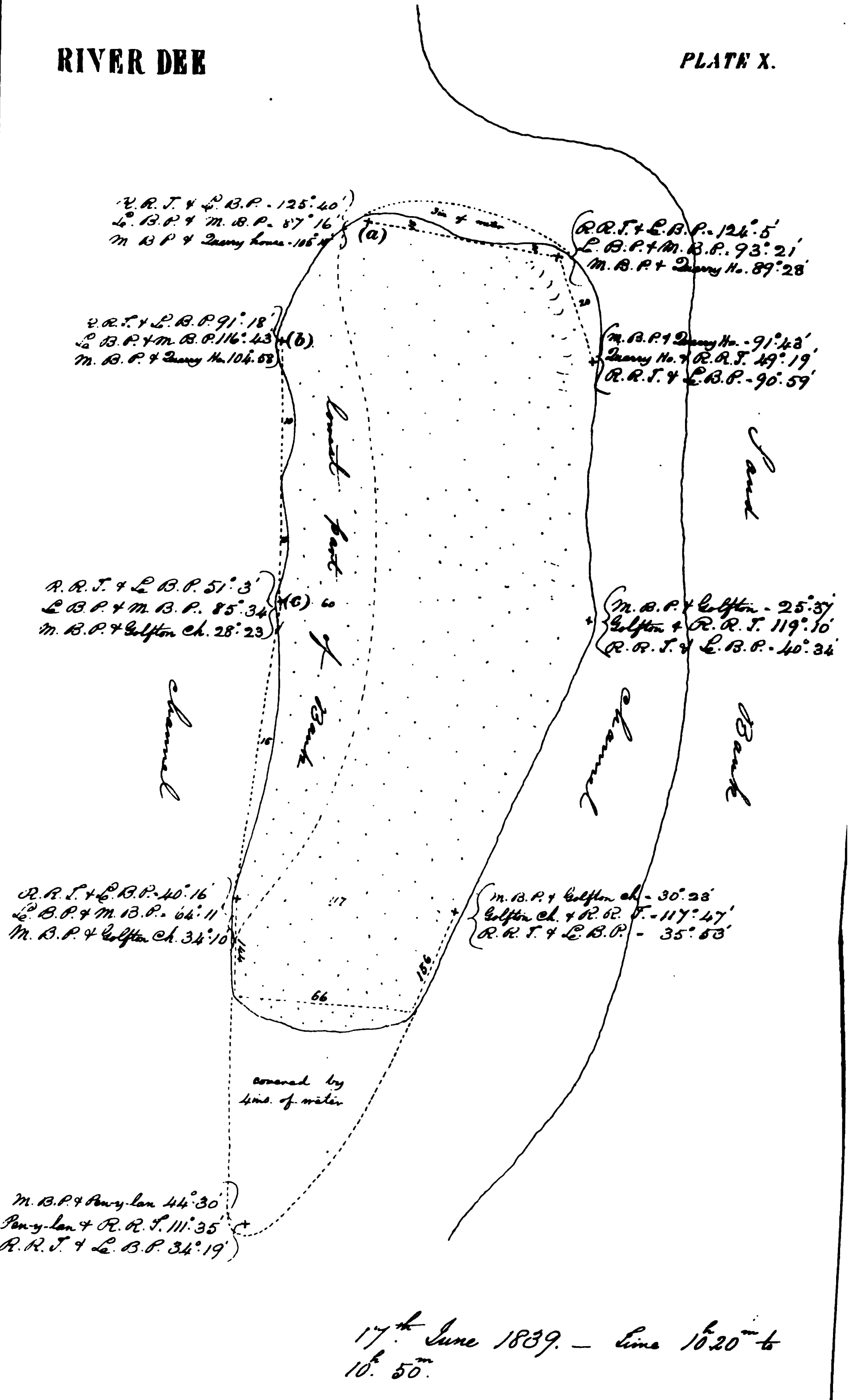
The surveys of the low water lines of beaches, banks, or rocks, which are situated in the sea, and are made in reference to harbour improvements, should be conducted only during low water of spring tides, as it is at such periods of the tide alone that a correct view of the bottom can be obtained. If this be overlooked, numerous omissions and er-

rors may be introduced into the survey, as there are many banks and rocks which, during neap tides, are covered to the depth of 2 or 3 feet, and consequently invisible, and liable to escape notice, but which are left quite dry, and can be easily and accurately surveyed at low water of springs. But in rivers and estuaries, the levels of whose beds are above the level of low water of neap tides, it is of no importance whether the survey be made during neaps or springs, as the former will evidently ebb sufficiently far to leave the whole of them dry, so as to admit of their accurate delineation.

It is in the department of the survey of which we are now treating, that the stations and points fixed by the triangulation will be found most serviceable; for although a surveyor, unacquainted with the use of the sextant, may fix the positions of the soundings, as explained in the preceding chapter, by observations made from theodolites placed on the shore, that method of observing could not be applied on a large scale to surveying the sand banks. Nor is the system of traverse surveying with the chain and theodolite, as recommended for the banks of the river above high water, and described hereafter, in any way better adapted for that purpose. There is only one mode of proceeding with which I am acquainted that can be advantageously adopted for this part of the work, and that is, to traverse the whole of the low water lines of the river, taking angles with the sextant at every prominent point or bend, to at least three known objects on the shore, in the manner already explained for determining the positions of the soundings; the spaces between the points of observation being

RIVER DEE

PLATE X.



sketched in by the hand as the survey proceeds with as much accuracy as possible. It may be conceived that this mode of surveying is not sufficiently detailed for the important part of the survey to which it is applied; but it must be kept in mind that the outlines of the sand banks and the low water channels of all rivers and estuaries are liable to constant changes produced by spring tides, high winds and land floods, and therefore, (considering the shortness of the time that can be devoted to this department), a more minute or detailed survey than that alluded to would be needless.

This system of surveying will be best understood, and the method of registering the observations most easily explained, by a reference to Plate X., which is part of a field book, shewing the survey of a sand bank in the river Dee. It will generally be found advisable to make the sketch on a larger scale than is shewn in the plate, the example given, having, for convenience, been somewhat reduced from the original. A quarto field book has the form and size of page on which the work can be most conveniently registered.

Referring to Plate X., we shall suppose that the survey of the bank commenced at the point marked *a*. The observer in this case, standing close to the edge of the water, took three observations, in the manner described at p. 65, to four points on the river, whose positions were known, namely, "Red Rock Tower" (which, to save time and room in registering, is marked R. R. T.), "Lower Barrel Perch," ("L. B. P.") "Middle Barrel Perch" ("M. B. P."), and "Quarryhouse," which were sufficient for determining the

position where he stood. He then proceeded along the edge of the bank until he came to *b*, a projecting point, where he took a second series of angles, in order to fix its position. In this case the line of bank between the two points *a* and *b* was nearly regular, and is so sketched in the field book. He next proceeded to *c*, but between *b* and *c* it will be observed that there are two small indentations from the straight line joining *b* and *c*, which are marked 10 feet and 15 feet respectively. The exact positions and amounts of these indentations could have been determined by taking angles with the sextant to known points on the shore at the places where they occurred, as in laying down the more prominent points of the bank; but in order to save time, they are sketched in the field book in the manner shewn, and the dimensions *paced*, or more generally, for small distances, measured only by the eye, approximations which are sufficiently accurate for all practical purposes, owing to the variations to which the outlines of the banks are subject, from the causes already alluded to. In this way the whole outline of the bank was traversed, and the field book made out as shewn in the plate.

When the lines to be surveyed in this manner are intricate, and the observations to be made very numerous, it is sometimes found convenient, in order to prevent confusion, to keep the field book in a form which differs somewhat from that shewn in the plate, and may be used on all occasions, if found more convenient. A sketch of the bank which is surveyed, is made on one page of the field book, and all the points on the sketch at which angles are taken are numbered 1, 2, 3, 4, &c. The angles taken at

the different points are entered on the opposite page, every series of angles having the number of the point at which they were taken placed opposite to it; and in this way, while no mistake as to the positions of the angles can be made, all confusion is avoided, and ample room left in the field book for sketching and remarks.

It is proper that the day and the time when the observations were taken, as shewn in the example given, should be noted in the field book, and thus the observer is enabled to make any correction that may be required to compensate for tide or flood in the river, which may be so gradual in their rise as to be imperceptible at the bank to be surveyed, but would nevertheless be easily detected by referring to the tide gauges.

From the example of the field book that has been given, and the explanation that has been made regarding this mode of surveying in laying down sand banks, its application to any other purpose, such as surveying the low water lines or the outlines of rocks, cannot fail to be readily understood, and it is therefore conceived to be unnecessary to give any farther examples in illustration of it.

Two persons, one to take the angles, and another to register them and make the sketches of the banks, are required for the proper performance of this system of surveying. But in the survey of low flat banks, which are dry only during a very short time, it is sometimes convenient, in order to expedite the work, to employ two or even three observers with their assistants, who ought to proceed to different points with their sextants, and thus, by dividing the duty, the survey of the whole bank may be completed in one

tide. A boat and crew must also be in constant attendance, not only for carrying the observers across the channel when necessary, but for the more important purpose of preventing the serious consequences that might ensue from their being surrounded by the tide, without the means of extricating themselves.

In situations where the tide is rapid and comes in with a *head* or *bore*, this should be particularly attended to, care being taken to arrange the work so that the observers may be in the immediate vicinity of the boat (from which, in the course of the survey, they must often be far removed) about the time when the tide may be expected to make its appearance. I have seen instances in which serious results might have ensued, had a boat not been in immediate attendance at the coming of the tide.

One great cause of danger on such occasions arises from the difficulty of knowing from what direction the flood tide will first make its appearance. It does not, as might naturally be looked for, invariably ascend the low water channel of the river, although its bed is always on a lower level than the banks on either side; but in some situations first appears by flowing over the sand banks into the regular channel of the river, where it joins the downward current of fresh water, and, along with it, continues to flow toward the sea, until their joint effect is neutralized by meeting that branch of the tide which forces its way up the proper channel. The branch of tide which first makes its appearance in the manner described therefore undergoes certain changes in the direction of its motion, which are somewhat curious. The direction imparted to it before leaving the great tidal

wave of the ocean is first wholly reversed, for it flows toward the sea along with the fresh water of the river, and this new motion is next completely checked, and again reversed, by the same tidal wave from which it emanated, and of which it may be said to form a part.

The flow of the tide is in this respect occasionally attended by very unexpected circumstances, and as these may sometimes come under the notice of the engineer in the practice of marine surveying, it may not be uninteresting or uninstructive to give an example of these apparent anomalies, with an explanation of what appears to be the cause of their occurrence.

The most remarkable one with which I am acquainted occurred to myself on the river Dee, near Flint, where the estuary is about 3½ miles in breadth, and the low water channel, which winds through a large extent of sand bank, is very tortuous. In the accompanying diagram, fig. 5., the

Fig. 5.

letters *a b c d* represent the low water channel, the direction of the current being shewn by the arrows. In examining

minutely the windings of the stream in reference to certain investigations, it was necessary to walk down the right bank of the river at low water, close to the edge of the channel. While so engaged, I crossed, at the point *b*, a hollow or depression in the sand bank, which, though sunk below the general level of the bank, was nevertheless quite dry, the lowest part of it being raised considerably above the level of the water in the river opposite to it. I had only advanced a very few steps after crossing this hollow, when I heard the rushing noise of the approaching tide, which, as it was at the height of springs, was expected to come in with great rapidity. Expecting to meet the tide forcing its way up the channel of the river, I continued to walk on, but seeing no appearance of it, and hearing the noise gradually increasing, and apparently coming from behind me, I began to suspect that all was not right, and on turning round perceived, to my great surprise, a rapid run of water flowing (in the direction shewn by the arrows in the cut) through the hollow which I had just crossed, and joining the river at *b*. I immediately hastened back towards the boat, which waited for me a little higher up the river, and after having waded through the newly formed stream, which had attained a depth of 6 or 8 inches by the time I crossed it, I stood on the upper side of it to see the result of this unlooked for inroad. The water continued to rush through the hollow, rapidly gaining breadth and depth, and at last, after an interval of probably two or two and a half minutes from the time at which the noise was first heard, the tide appeared forcing its way up the channel of the river, and, joining the current which rushed through the hollow *d b*, the

sand bank *b c d* was soon encircled by a broad and deep boundary of water, rendering all access to it or egress from it quite impracticable unless by a boat.

This, it is believed, is only one of many instances of such a precursor of the regular tide which are to be found in situations where the flood sets in rapidly, and it shews with how much caution those engaged in this sort of surveying ought to conduct their operations.

An explanation of the cause of this phenomenon may be found in the circumstances attending the rise of the tide, as illustrated in the several diagrams of the tidal lines already given and described in the preceding chapter. It will be recollected, that, at some periods of flood tide, the level of the water was considerably higher in the lower than in the upper parts of the navigation. In the case of the Dee, indeed, where the peculiarity in the flow of the tide for which we are attempting to account occurred, the level of the water at Flint was found on one occasion during flood tide to be 7 feet 10 inches above that at Chester, the surface of the river thus forming an inclined plane from the sea downwards. Now this inverted order of things would naturally exist during certain states of the tide at the part of the river at which the phenomenon I have described was observed, or, in other words, the level of the water at *d* in the diagram, would be above that of the water at *b*. Without observations made for the special purpose of ascertaining the fact, it is impossible to say what the maximum difference of level during flood tide might be; but on the supposition that the distance by the channel *d c b* was a mile, we may infer from an examination of the diagram of the tidal lines already al-

luded to, that the difference in height between the two points would be considerable. We shall suppose, then, that the tide, on arriving at the point *d*, divides into two branches or currents, and that one proceeds up the channel of the river towards *c*, while the other flows into the hollow in the sand bank at *d* towards *e*. Now, as the level of the water at *d* rises, the stream which has flowed into the hollow in the sand bank gradually rises higher and higher upon the bank, until it surmounts the summit level, which we may suppose to be at *e*, after which it rushes from *e* to *b* without obstruction. In the mean time, the other branch of the tide is forcing its way against the stream of the river by the long circuitous channel *d c b* having a greater distance, more friction, and the current of the fresh water to contend with; and before it reaches *b*, the water at *d* has attained a much higher level than that at *b*, and has even *overtopped* the summit level of the sand bank at *e*, and is flowing without obstruction into the channel of the river in the manner represented to have taken place on the Dee. Thus, in all cases where the retarding influences which exist in the regular channel of the river exceed the retarding influences in any *back lake* or *swash way*, the tide will flow through the latter sooner than the former, and give rise to an anomaly such as I have described.

CHAPTER VI.

SURVEY OF HIGH WATER MARGIN.

Objects of the survey of the high water margin—Two systems of surveying employed for this purpose—Chain and traverse surveying—Use made of the triangulation stations—Description of the process of traverse surveying—Directions for adjusting the theodolite—Reverse bearings—Method of keeping field book—Example from survey of the Tay—Checks on the accuracy of the field work—Method of surveying outlines of extensive tide covered marshes.

It is generally necessary that the high water margin of a river or an estuary should be distinctly defined, in order that the conservators of the navigation may know the boundaries to which the powers granted by their acts of parliament extend. These powers are occasionally brought into action for the purpose of preventing the proprietors of the surrounding land from erecting works within the high water mark, in order to extend the limits of their property, especially when these works prove injurious to the navigation, either by curtailing the tidal capacity of the river to a serious extent or interfering with the fair-way. In other cases, again, land may be reclaimed without impairing to a hurtful de-

gree the tidal capacity of a river, or injuring its navigation; and in such situations, works, erected expressly for its improvement, often have a direct tendency, by encouraging the deposition of silt and mud to hasten the process of "land making." But as the conservators of the river in these cases have generally power by their act of parliament to make certain claims on the proprietors, for all the land that has been taken from the bed of the river and added to their property in consequence of such operations, the means of determining the extent of land that has been reclaimed must be afforded.

In all cases where land is reclaimed, the high water margin is of course changed both in its form and position. It is therefore necessary for the settlement of questions relative to land that the whole of the shores be accurately surveyed in such a manner that the original marginal line of the river may, at any period, be traced by reference to fixed objects on the banks, whose relative positions cannot vary. When the survey has been completed and the poles removed, stone marks should therefore be sunk in the ground at the sites of the different triangulation stations, so that their positions may at any future period be easily discovered; and the survey of the margin of the river, which is the subject to be treated of in the present chapter, should, in accordance with these views, be made to embrace all houses or other remarkable objects whose positions are not likely to be changed, and which lie within 200 yards of the high water mark.

Two different systems of surveying may be employed for delineating the margin of the river. The one is that of "chain surveying," which is adopted by land surveyors, and

being founded entirely on measurements made with the chain, is best suited to situations where the distances between the triangulation stations are not very great. The other is that which is called "traverse surveying," a system in which the lengths of the lines are measured by the chain, and checked by angular observation, and their directions are determined by means of the theodolite. In either case, the stations of the triangulation ought to be regarded as points whose positions have been finally determined, and the survey of the banks should be divided into a series of smaller surveys or compartments quite independent of each other, and extending between the different triangulation stations. If an error happens to be made in the field work, its effect is, by this arrangement, confined to that compartment of the survey in which it was committed, and does not extend beyond the fixed points by which it is limited.

As little more than the mere outline of the shore of a river requires to be represented, the system of traverse surveying is most applicable for that purpose. When compared to the method pursued by land surveyors, it saves time and insures greater accuracy, especially when the distances between the triangulation stations are considerable. It is often convenient, however, for the engineer to confine his operations to the triangulation, and the survey and soundings of the tidal area within high water mark, leaving to land surveyors the survey of the margin of the river extending between the different stations. In that case, the land surveyors of course adopt the systems they have been in the habit of using, but where they are not employed, and the survey is to be made by the engineer's own assistants,

it is believed it will be found most convenient to employ the system of traverse surveying, on which I shall therefore make a few remarks.

This method of surveying, as is generally known, consists in measuring a series of straight lines along the margin of the shore to be delineated, in determining the directions of these lines, and in obtaining data for checking their lengths by angular observations. Offsets taken with a tape-line from the lines so measured and determined, to all prominent points, give their exact positions.

The survey may be commenced at any of the triangulation stations; and that the bearings to be taken may be connected with the triangulation itself, the instrument should be adjusted so that, when directed to any of the other stations, the bearing indicated by the reading vernier shall be the same as that originally obtained from the same point, when the triangulation was made. While the instrument is being thus adjusted at the triangulation station, an assistant should be sent forward to fix a surveying pole (which, in explaining the system, we shall call station *a*) in the direction in which the first line of the survey is to be measured. He should take care to place it in such a situation that as long a line as possible may be obtained from station *a* to the next station, which may be called *b*. When the pole has been adjusted, an observation must be taken to it with the theodolite and registered in the field book. The measurement of the line and offsets is then commenced, a sketch of the outline of the shore or bank being made, and all the distances carefully marked on it as the survey proceeds. On arriving at station *a*, the whole length of the measured

line ought to be registered in the field book under the bearing. To prevent confusion, it is advisable to number the lines in regular order as they occur, and to attach letters of the alphabet at each extremity, the letter (as a') which stood at the end of one line being placed in an accented form (a') at the beginning of that which succeeds it.

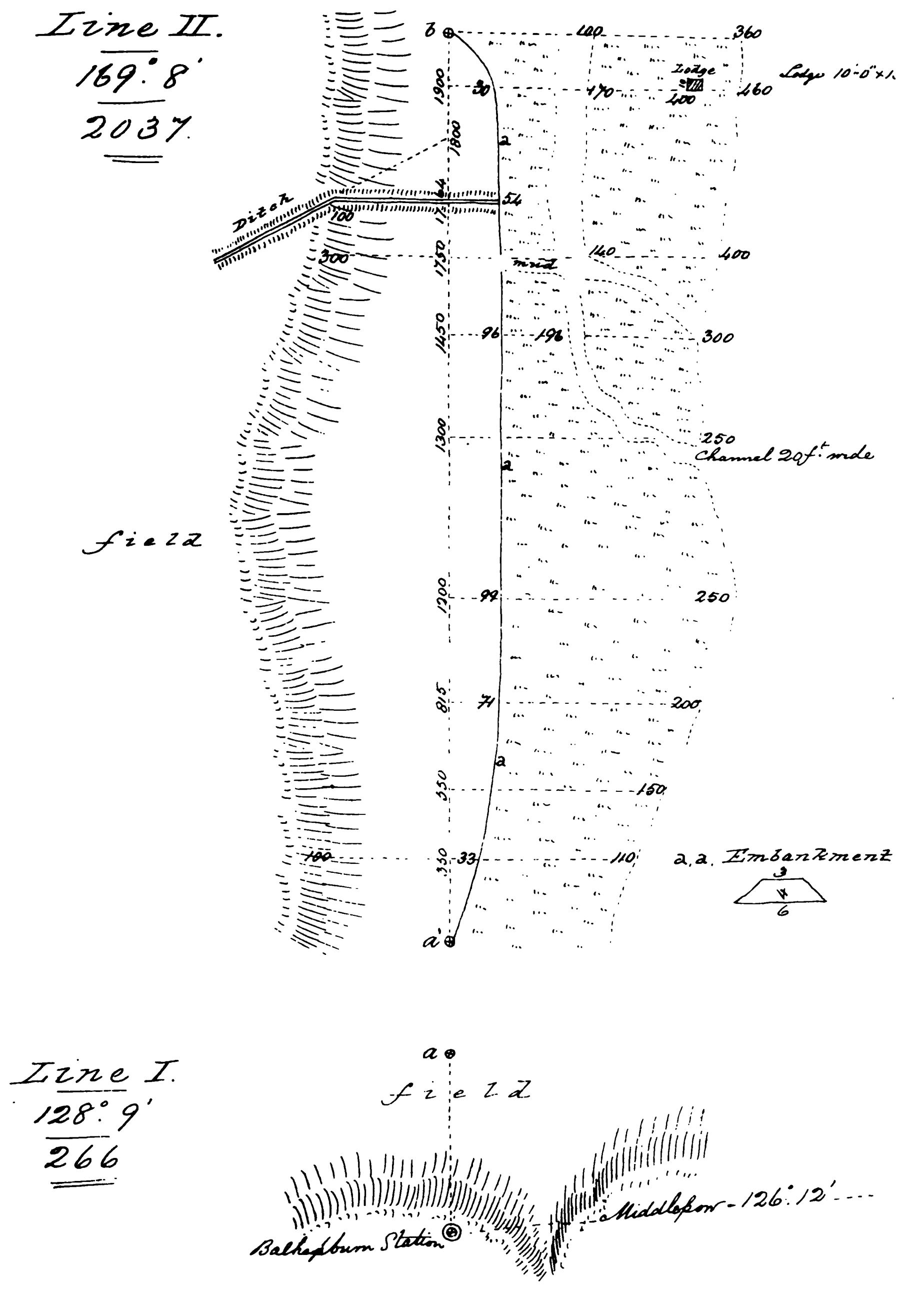
In order to adjust the instrument at a (the point at the termination of the first measured line), it ought to be set at the angle which the survey line bore, and directed back to the triangulation station from which the survey commenced. Bearings should then be taken to any of the triangulation stations within view, for the purpose of checking the measurement of the distance. While these observations are being made, an assistant advances in the direction in which the next line is to be measured, and fixes the station pole, which may be called b, in the same way as has already been noticed. The bearing of b is then taken and noted down, and the measurement of the line commenced. A station pole must be left at a to mark its position, as the back bearing must be set to it from the point b, before the bearing of the next line, which would be to station c, can be taken.

It seems almost unnecessary to say that it is of much importance in this, as well as in all departments of surveying, to be able to keep a distinct field book, as it insures great facility as well as accuracy in the protraction of the work. But exactness in this respect can be attained only by practice. The sketching necessary for this purpose is of quite a different nature from that of which a knowledge is required in landscape drawing or painting, for the representa-

tion of the surface of the ground is not laid down in proportion by the surveyor; the size of the offsets, or, in other words, the breadths being greatly exaggerated in comparison to the lengths. The tendency which beginners have to keep up the proportions of length and breadth as they appear to the eye, is the great difficulty to be overcome in attempting to keep a good field book.

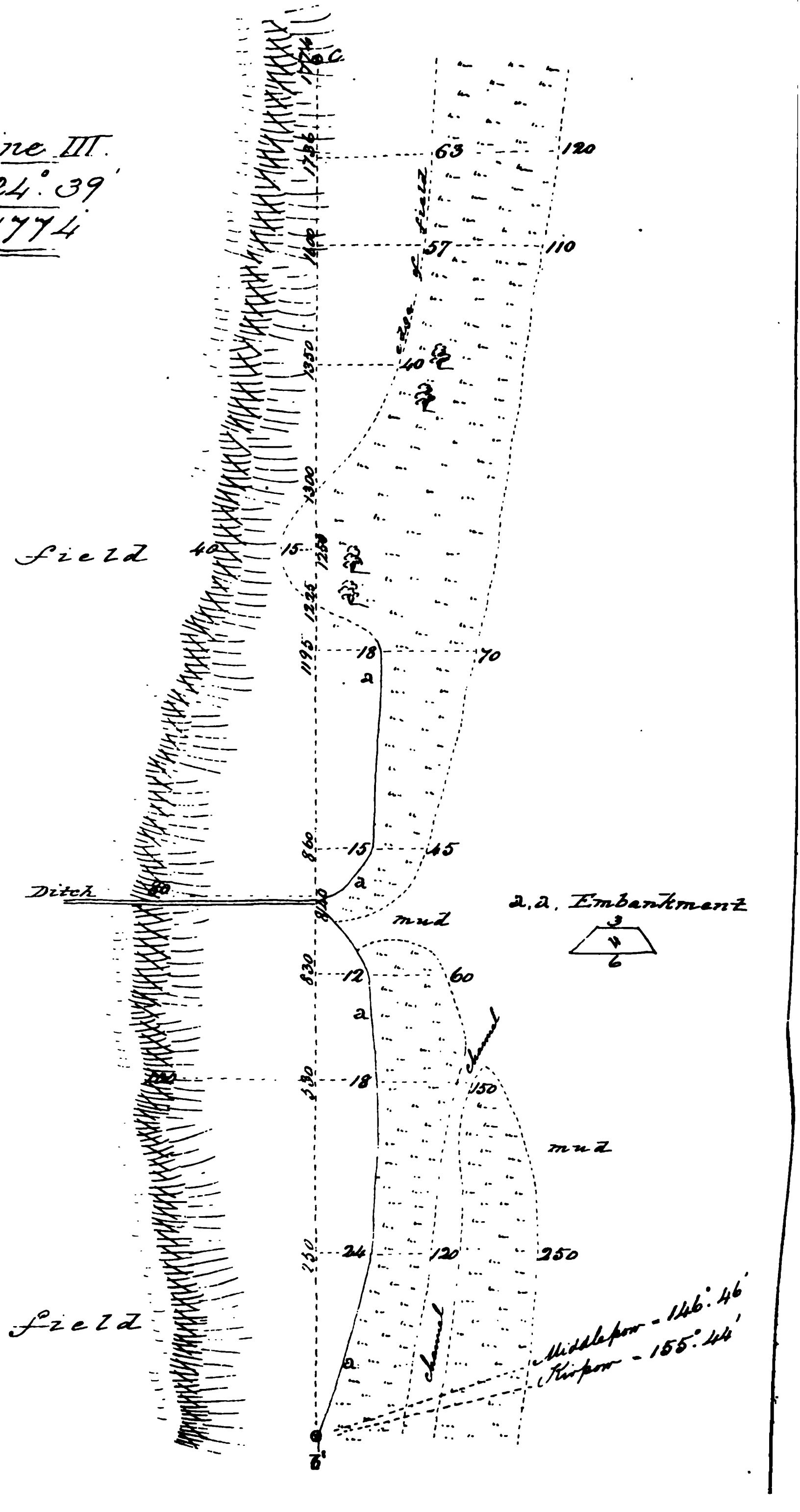
I have given an example of a field book of part of the river Tay, to shew in what way it should be kept, and a reference to it will perhaps serve to render more intelligible the explanation of this system of surveying which I have attempted to give. Plate XI. represents a page of the field book, and contains two short survey lines. The first is marked line No. I. in the corner of the field book, and commences at Balhepburn, one of the stations of the triangulation. The theodolite on this occasion was directed to Middle Pow, another of the triangulation stations, set at the angle of 126° 12′, which in this case was adopted as the primary bearing of the survey. The bearing to *a* 128° 9′ was then taken and registered, after which the line was measured, and its whole length, 266 feet, also registered. No offsets required to be measured on this short line, which extended between the station and the edge of the river. At *a′* (Plate XI.) the theodolite was set back on Balhepburn station with a bearing of 128° 9′. The bearing of *b* 169° 8′ was then taken and registered, and the length measured. Offsets were taken to all remarkable points, the distances at which they occurred being noted on the dotted line in the field book, which represents that measured on the ground. On arriving

RIVER TAY. *PLATE XI*



Survey of the Tay from Balhepburn station westward. October 3d 1833.

RIVER TAY. PLATE XII



at *b* the termination of the line, the whole measured distance 2037 feet was registered. I now refer to plate XII, in which *b′* at the commencement corresponds with *b* at the termination of the last line in Plate XI., both of the letters representing the same point on the ground. The theodolite, with the bearing of the last line, viz., 169°.8, was then set back upon *a′*, the surveying pole having been left standing for that purpose, and angles were taken, as shewn in the plate, to Middle pow 146° 46′, and Kirpow 155° 44′, two stations of the triangulation, in order to give the means of checking the measured distance in protracting. In conclusion, the bearing of the next line or the pole at *c* was taken and registered as 324° 39′. This line was then measured, and offsets taken as formerly, the distance being registered at 1774 feet. It is to be observed, that when a line is very long, or where its intricacy renders it necessary to shew it on a very large scale, one page of the field book may not be sufficient to contain the whole of it; and in that case, it is carried to another page, and noted as a continuation of the preceding line.

The whole coast of the river is surveyed in the manner described, the lines following the contour of the shore, the straightness or crookedness of which determines their number and lengths, until another triangulation station is reached, at which point the accuracy of the angular part of the survey may be tested. It will be observed that the method of using the back bearing in traverse surveying is simply an extension of the same system which is practised in making the triangulation, in which, as explained in Chap. I., the corresponding bearings at different stations are parallel to each other; and, consequently, if the primary bearing of the

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traverse survey at the first or starting station be made to coincide with the same bearing in the triangulation, it is evident, that, when the instrument has been adjusted on arriving at a second triangulation station, the bearing taken from it to any third one, will, if the work be right, be either the same bearing as that formerly observed, or the one on the opposite side of the horizontal limb. If this be not the case, it may be inferred that some error in the observation has been made, and the angles must be observed again. To permit this to be done, it is a necessary precaution to place a mark, such as a peg of wood, in the hole formed by every setting of the surveying pole, which may remain until the angles have been checked in the manner explained. In conformity to the same principle, namely, that of the parallelism of the corresponding bearings, it is evident that the direction of the magnetic needle, under the limitations for variation mentioned in Chap. I., may be used at the different stations, to ascertain whether any great mistake has been committed; for, if the work be correct, the needle, if unaffected by local attraction, will point to 360°, or 180°, at every station when the instrument has been adjusted for observation, and the vernier set at 360° on the horizntal limb.

In situations where the margin of the sea or of the river has a large tract of tide covered marsh land in front of it, whose level is but a few inches below that of high water, a formation often met with, the system of surveying recommended for laying down the sand banks may be advantageously combined with that of the traverse surveying which has been described. I have known cases where such marshes,

covered only at very high tides, and often affording excellent pasturage, extended upwards of a mile from what might be termed the high water mark of the river. Such tracts of land, although only occasionally covered by the tide, ought, nevertheless, to be included in the survey of the margin of the shore. But as it would be unnecessary, as well as inconvenient, to employ the same minute mode of surveying in the delineation of their variable outlines, as in that of the more permanent margin of the river, it is better to combine the two systems, applying, to what may be considered the permanent margin, the mode of traverse surveying, as explained in the present chapter, and laying down the outlines of the marshes as the traverse survey proceeds, by sextant observations, in the manner already explained in treating of the surveys of sand banks. The determination of the cases in which the one or other, or a combination of both of these systems of surveying is most applicable, must be left to the discrimination of the surveyor.

CHAPTER VII.

CROSS SECTIONS AND BORINGS.

Uses of the Cross Sections and Borings—Situations in which they are required—Reference of Sections and Borings to datum line of survey—Directions for making Sections—Description of apparatus employed, and its application—Directions for making Borings—Description of apparatus, and its application—Method of keeping Field book—Importance of this department of the survey, as affecting designs for works—Example of this in the case of the river Ribble, in Lancashire, and the Fossdyke, in Lincolnshire.

THE department of the field work to be next noticed, is that of making sections and borings, which are indispensably necessary in all cases where hydraulic works are to be executed. In deepening a navigation, or the entrance to a harbour, for example, these operations furnish the data for ascertaining the quantity and quality of the materials to be removed, in order to obtain a certain depth of water, while, by discovering the composition and form of the bottom, they enable the engineer to select the most eligible site for excavating a navigable channel, founding a pier or breakwater, or any other hydraulic work.

In surveys of rivers, made expressly with reference to the improvement of their navigation, sections and borings are, in general, required only at those parts of the channel

where fords or shoals occur, or any obstructions which need to be removed, no intermediate observations being necessary. But where rock is found at intervals in a river's course, in some places quite bare and exposed to the run of the water, and in others covered to a considerable depth with gravel, sand or any other deposit, it is necessary to make the sections and borings at shorter intervals, in order that the formation of the bed may be ascertained with sufficient accuracy to enable the engineer to form designs for works, and estimates of their expense, with either advantage or precision.

Much time may be lost in making the sections and borings, and erroneous data may be obtained, if the operation be not gone about in a proper manner; and I conceive that this treatise would be incomplete, were I to omit offering a few remarks on what I have found, in practice, to be the best system in conducting this very important department of an engineer's survey.

In the first place it may be stated, that it is advisable carefully to examine the whole course of the river, and to select the places at which sections and borings are required, before commencing to make any of them. In making this selection, the engineer can be guided only by the object of the investigation and the formation of the river's course. If there be fords or shoals in the bottom which occasion obstructions to the navigation, and require to be removed, one or more lines of section may be fixed on at each shoal, according to its extent, and the positions of the lines selected should be marked by wooden stakes driven into either bank of the river. Where, as sometimes happens,

the channel is irregular, or has rock occurring at various points, it is often necessary to obtain, by means of numerous cross sections, an exact survey of the whole, or at least of a great part of the bed, before any distinct plan of operations can be formed; and in that case, a series of stakes must be fixed on the margin of the river, at equal distances of 100 feet or 200 feet apart, according to the minuteness of the investigation to be made. In every case the stakes employed to indicate the positions of the sections should be regularly numbered with a marking iron, in the order in which they occur in the river, to prevent the possibility of one section being mistaken for another; an accident which is not unlikely to occur when the breadth of the river is pretty regular and the banks do not present prominent objects, by a reference to which the positions of the lines may be determined. The stakes so fixed should be noticed in making the traverse survey of the banks, and in this way their sites may afterwards be correctly protracted on the plan.

That the depths of the sections and borings may be referred to the same datum as the soundings of the depths of water treated of in Chapter IV., the levels of the wooden stakes which mark the positions of the lines in which they are to be made, should be fixed in reference to that datum. To save time and a multiplication of observations, it ought to be done while the levels for ascertaining the relative heights of the tide gauges are being taken; but if this arrangement be not convenient, a separate series of observations must be made with this object specially in view.

I shall now suppose that the positions of the different

lines of section and boring have been selected and marked by stakes, and that the levels of these stakes, in reference to some datum line have been ascertained, and shall proceed to offer a few remarks on the method of conducting the operation of making the sections and borings themselves.

The most favourable time for making both the sections and the borings is during low water, when there is no land flood, or, in other words, when the river is at its "summer water level." It will invariably be found that the apparatus employed can be much more easily used, and the results obtained in a more satisfactory manner, under these circumstances, than when the river is increased in breadth and depth, or the velocity of its current augmented, by either the tide or land floods.

When the breadth of the stream exceeds 200 or 250 feet, and the soil in the bottom is sufficiently soft to admit of it, one or more iron bars (according to the breadth of the stream) about $\frac{7}{8}$ths of an inch in diameter, and 14 or 15 feet long,* should be fixed upright at convenient intervals in the bed of the river in the line in which the section is to be made. A strong cord graduated at every 10 feet with leather marks, having the figures distinctly shewn on them, should then be stretched across the river; one end of the cord being made fast to the section stake, and the other to an iron rod, or some such fixture, driven into the opposite bank of the river. When the line has been extended be-

* Rods, measuring 15 feet, are generally sufficiently long for the low water depths of our rivers, especially when it is considered that the sections, to which I am at present alluding, are made only at the shallowest parts where obstructions to the navigation occur.

tween these two points, and hauled as tight as seems consistent with its strength, it should be raised and secured to the several iron bars that have been fixed in the bed of the river, at as great a height above the surface of the water as can be conveniently reached from the boat. The intermediate supports thus produced are for the purpose of shortening the points of suspension, and preventing the cord from floating on the surface of the water; for the marks cannot be distinctly seen when it is in that situation, and if it remains for any length of time so immersed, the current gradually stretches the line, altering both the direction and the distances, and occasioning great inconvenience. Doubts may exist in the minds of some as to the sufficient accuracy of the graduation of a line which has to undergo the repeated alternations of wetness and dryness thus produced, and which is so frequently stretched; and objections to the method of tying it up to the iron rods may be started, on the ground of its forming a series of curves instead of a straight line. But such doubts and objections refer to quantities of comparatively small importance, and may, I am convinced from experience, be safely disregarded in practice, which is the chief object to be kept in view in the present inquiry. I have made many sections in the manner described, varying from 100 to 800 feet in length, and in no case have I met with any practical error or difficulty in consequence of the length of the section line differing materially from the breadth of the river, as obtained trigonometrically in the course of the survey. It is advisable, however, that the cord to be used should be properly wetted and stretched before being graduated; and

its length should likewise be occasionally checked in the course of a survey of long duration.

The cord having been adjusted in the manner described, a section of the bank of the river extending from the stake which marks the position of the section line to the edge of the water should be made with the spirit level and rod in the usual way; the stake being taken as the datum for the levels, and the zero for the distances. When this has been completed, soundings are to be taken with a sounding rod across the river, from bank to bank, at intervals of 10 feet, as marked on the graduated cord, after which a section, or, more strictly speaking, a continuation of that already made on the opposite bank of the river, is to be extended from the edge of the water to the high water mark, or as much farther as may be considered necessary.

By these processes sufficient data are obtained, provided the water has not altered its level while they were in progress, for laying down an exact section of the bed of the river in reference to the stake on the bank. But should the flow of the tide happen to commence while the soundings are being taken, or should the survey be proceeding either during flood or ebb tide, the results obtained would evidently be inaccurate, and require correction in consequence of the change of level which would, in the cases mentioned, take place on the surface of the water. In order to enable the observer to know when a change of level occurs, and to correct his observations according to the amount of that change, it is obvious that he must be able, at any particular moment, to ascertain the height of the water as compared with what it was at the commencement of the soundings when the

level of its surface was fixed in reference to the datum line. For this purpose it is necessary, as soon as the section of the bank has been carried to the water's edge, and before the soundings have been commenced, to drive a short graduated tide gauge into the bank of the river, with its zero, or some known point, at the level of the water. In this way, if the water either rises or falls, the amount of difference in level can at once be discovered, and the depths of the soundings corrected by referring to the gauge.

The borings, or more properly speaking, *probings* to which I shall now allude, though of great importance, are of a comparatively superficial nature, being confined to the depth below the bottom to which the intended operations are likely to extend. This, in ordinary cases, is very limited. They are made with iron rods about 18 feet in length, and one eighth of an inch in diameter, *steeled* at the points, and graduated to feet and half feet with chisel marks. If more extended observations are required in this department of the survey, which is sometimes the case, they must, of course, be made with boring rods by persons qualified to execute such work, the nature of which it is unnecessary to enter on in this place.

The borings with which we have to do, however, although superficial, generally occupy much more time than the section; and it is advisable, that while one party has been making the preliminary arrangements and observations, and taking the soundings and levels for the section, in the manner already explained, another party should be going on with the borings. For this purpose, it is necessary to determine at what intervals they are to be taken, and to instruct the person who is to take charge of the boring de-

partment accordingly. When rock occurs within the depth to which the operations may be expected to extend, the intervals between the borings should not exceed 10 feet; but in other situations, every 30 or 40 feet may be sufficient, according to the nature of the bed of the river. The person who makes the borings must register the distance of each, as indicated by the graduated cord, and the depth to which it extends below the bed of the river. This may readily be ascertained by deducting the depth of water at the spot from the whole depth indicated by the graduation on the boring rod, before it is withdrawn from the bore. The nature of the stuff as to hardness or softness should also be registered, with any other remarks, bearing on the investigation, that may suggest themselves. The boring rods are *jumped* into the bed of the river by men working from boats; and when the stuff is too hard to admit of this, they are driven by blows from a light hammer. In the latter case, difficulty sometimes arises in drawing them, especially from tenacious marl or clay; but they can always be raised with a little trouble, by means of a purchase applied from the boat, after being started by the blow of a hammer. Rods of this kind are exceedingly convenient; and for the comparatively superficial, though highly important, examination referred to, are the simplest and best adapted apparatus I have ever used.

For further illustrating the operation which I have attempted to describe, I add a page of a field book, containing the notes of observations taken in making a line of section and borings on the river Ribble.

The first table marked No. 1. is the register of the levels

on one side of the river, and contains the sights from the section stake to the water's edge. By this it appears that the fall from the section stake to the surface of the water is 7.30 feet. To this fall there is added 1.78 foot, the fall from the datum line to the stake, which is ascertained in the manner alluded to in page 94; the total fall from the datum line to the surface of the water being 9.08 feet. The fourth column of this table contains the distances, and the last, remarks.

The table marked No. 2. refers entirely to the sections and borings of the bottom of the river. The figures in the first, third, and fifth columns, are filled in on the ground. Those in the second and fourth columns represent the depths reduced to the datum. This is done by adding to the depths of the soundings and borings, the fall from the datum line to the surface of the water. In this case the fall, as shewn by table No. 1., is 9.08 feet; but in making the corrections, the decimal part .08 is rejected, and 9 feet assumed as the constant quantity to be added to all the depths. The protracted field work of this line of section and borings is represented in Plate XIII. fig. 2, to which the reader is referred for a farther explanation of the subject.

FIELD-BOOK.

No. 1.

Cross Section of River Ribble, at Stake No. 15, 25th July 1838.

LEVELS.

Sights.	Rise.	Fall.	Distance.	Remarks.
2.68 3.84	. . . . .	1.16	35	On Stake No. 15.
3.84 9.98	. . . . .	6.14	92	At edge of water.
		7.30	. . . . .	Surface of water below stake.
Add fall from datum line to stake,		1.78		
		9.08	Surface of water below datum.	

No. 2.

SOUNDINGS AND BORINGS.

Depth of Water.	Corrected Depth of Water below datum.	Distance.	Corrected Depth of Boring below datum.	Depth of Boring below Bed of River.		
Feet. in.	Feet. in.		Feet. in.			
0 9	9 9	100	19 9	10 feet through sand and gravel to rock.		
3 6	12 6	110	19 0	6.6	do.	do.
3 9	12 9	120	17 3	4.6	do.	do.
3 9	12 9	130	16 6	3.9	do.	do.
3 0	12 0	140	16 2	4.2	do.	do.
3 0	12 0	150	16 3	4.3	do.	do.
3 3	12 3	160	15 9	3.6	do.	do.
3 6	12 6	170	14 6	2.0	do.	do.
4 6	13 6	180	15 0	1.6	do.	do.
4 6	13 6	190	14 0	0.6	do.	do.
3 7	12 7	200	...	Bare Rock.		
2 6	11 6	210	...	Do. do.		
2 9	11 9	220	...	Do. do.		
2 6	11 6	230	...	Do. do.		
2 3	11 3	240	...	Do. do.		
2 0	11 0	250	...	Do. do.		
2 0	11 0	260	...	Do. do.		
2 3	11 3	270	...	Do. do.		
2 2	11 2	280	...	Do. do.		
2 0	11 0	290	...	Do. do.		
1 9	10 9	300	...	Do. do.		
5 3	14 3	303	...	Do. do.		
5 0	14 0	310	...	Do. do.		
5 0	14 0	320	...	Do. do.		
4 9	13 9	330	..	Do. do.		
4 9	13 9	340	...	Do. do.		
4 9	13 9	350	...	Do. do.		
4 6	13 6	360	...	Do. do.		
3 9	12 9	370	...	Do. do.		
3 6	12 6	380	...	Do. do.		
1 3	10 3	385	...	Do. do. at Quay Wall, 6 ft. high.		

The use of the cross sections and borings is to furnish data on which designs of improvements and estimates of their expense can be founded; and the correctness of an opinion, either as to the practicability or efficiency of a work, or as to the probable expense of its execution, may be said to depend, in almost all cases, on the minuteness and accuracy with which they are made.

As this department of the survey is of great importance, I may be excused for going into some detail regarding it; and I shall therefore, before concluding, endeavour to illustrate, by a reference to practice, the necessity of conducting it with care and accuracy.

The example to which I shall refer is taken from the case of the river Ribble in Lancashire. The upper part of this river flows in a bed composed of successive patches of solid sandstone rock, compact gravel and loose sand, the irregularity of which rendered an extensive series of cross sections and borings absolutely necessary before any design for the improvement of the navigation could be devised, or any estimate of its expense formed. These lines of section and boring, which were made throughout the whole of the upper part of the river, at distances of 100 feet apart, varied much in their character; some giving a bottom composed of sand, and others of hard gravel, while in certain places the bottom was found to consist of rock, quite exposed, or covered with a deposit of mud or gravel, varying from a few inches to several feet in depth. I have shewn two of these sections in Plate XIII. figs. 1. and 2., which, although made at the distance of only 100 yards apart, fully illustrate the variety in the results obtained, and shew the importance

Cross Sections and Borings of the River Ribble.

Fig. 1.

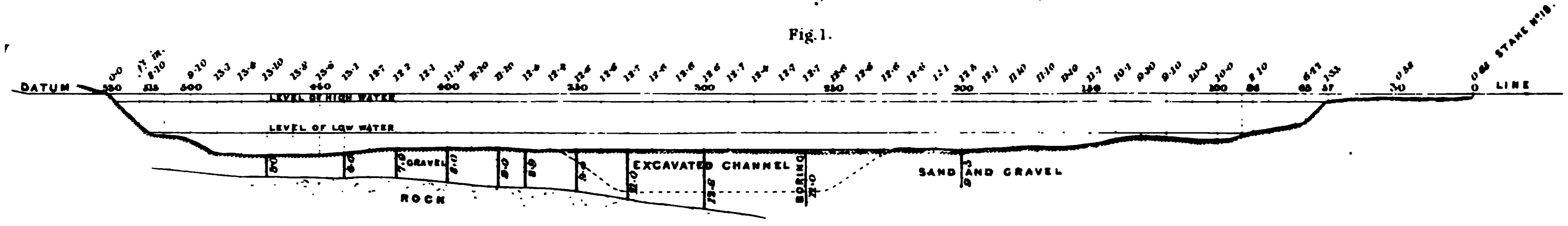
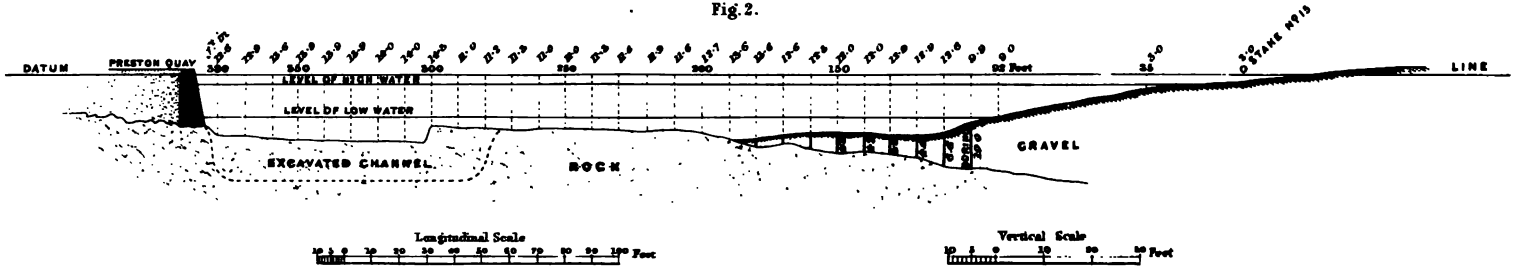
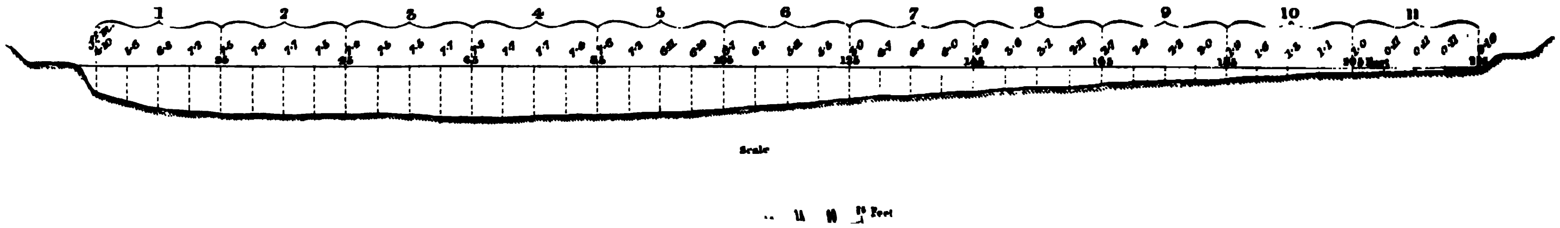


Fig. 2.



Cross Section of the River Conon.

Fig. 3.



of these inquiries in forming designs and estimates of such works.

In the first of these sections, it will be seen that the bottom of the river consists of gravel and sand, with rock underneath, at depths varying from 5 to 12 feet below the bed; in the second, on the other hand, the bottom is on as high a level as the first, and is composed of bare rock, without any deposit on it.

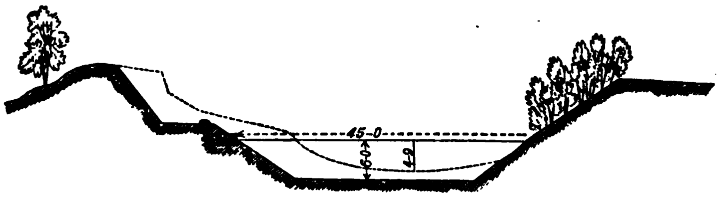
The new navigable channel, which has been excavated since the survey was made, is shewn on the sections in dotted lines; and, from an examination of the Plate, any one at all acquainted with engineering will at once perceive the great difference, as regards both expense and difficulty, which attended the execution of the work at the two places. In fig. 1 the operation consisted simply of dredging in sand and gravel, and was easily and cheaply accomplished by a dredging machine of the ordinary construction. In fig. 2 it consisted entirely of excavation in solid rock permanently under water. This excavation, which varied from a few inches to 13 feet 6 inches in depth at the deepest place, and amounted to 30,793 cubic yards, was executed by means of a series of cofferdams of peculiar construction, which were kept dry by a pumping apparatus worked by a steam engine,* a mode of excavating attended with very great expense when compared to the simple process of dredging required for forming the channel in section No. 1. These

* I have given an account of the details of this work, and the construction of the cofferdams designed for executing it, in a communication which was read before the Institution of Civil Engineers in 1841, and is printed in the Transactions of that body, vol. iii. p. 377.

widely different operations, however, occurred on the same river, at a distance of only 100 yards apart, and it is very obvious that, without a series of such sections, it would be impossible to form any opinion as to either the nature of the operations or the amount of outlay required for improving the navigation of such a river as that alluded to.

Many examples of a similar kind might be given, but it seems unnecessary to enter on them. I shall therefore close this chapter by referring to the accompanying cut (fig. 7.), which represents a cross section of the Fossdyke navigation in Lincolnshire in its former state, and also a view of the condition in which it is proposed to be placed by the operations at present in progress.

Fig. 7.



The dotted line represents the cross sectional area of the canal and banks in its unimproved state. The hard lines shew its enlarged limits, which at some places have been already attained. This example, as in the former case, tends to shew the necessity of minute and accurate sections, on which to base all calculations as to the extent and cost of the work to be executed.

CHAPTER VIII.

HYDROMETRICAL OBSERVATIONS.

Application of hydrometrical observations to engineering—Discharge of rivers—Making of cross section—Determining the velocity—Instruments for measuring the velocity—Floats—Objections to floats for this purpose—The tachometer of Woltmann—Description of instrument and its application—Adjustment of scale of tachometer for observation—Formula for reducing the surface to mean velocity—Table of mean velocities—Instrument for determining velocities of currents in the sea—Floats—Massey's log—Instruments for measuring under currents—The tachometer—The under current float—Instruments for ascertaining the directions of currents at sea—Obtaining specimens of water from different depths for the purpose of analysis—The Hydrophore—Varieties of construction—Manner of using them.

The preceding chapters refer to the different departments of the field work, by which data are obtained for constructing a plan or chart, and forming designs and esti mates of works to be executed.

Certain hydrometrical operations have now to be noticed in connection with the subject of marine surveying, which, though not required in making designs and estimates, must nevertheless be occasionally performed by the civil engineer in determining particular points relative to the improvement of navigations, the construction of harbours, or the adjustment

of the rights of neighbouring land owners in reference to salmon fisheries. The last of these subjects, although comparatively unknown in England, has, for a great length of time, occupied much attention in the Scotch courts of law, some of the cases involving intricate physical questions, the solution of which is, in many instances, effected wholly or in part by means of the data afforded by hydrometrical observations.

It is unnecessary in this place to enter into any detail regarding the nature of the various questions for the decision of which hydrometrical observations may be required.* It seems sufficient simply to narrate the different investigations in which the engineer may be engaged, and to describe the apparatus employed, and the method of conducting them.

I shall, therefore, without farther remark, observe, that it is often necessary in the course of the practice of engineering to determine the discharge of rivers, the velocity and direction of surface and under currents, and the quality of water taken from various depths and at different times of tide, as well with regard to the proportions of sea and fresh water which constitute the mixture, as to the quantity of solid materials, such as sand or mud, held in mechanical suspension.

A few brief remarks on the mode of conducting these investigations and the apparatus employed, will form the subject of this chapter.

* For further information on this subject, the reader is referred to the Reports to the British Association on "The Progress and Present State of our Knowledge of Hydraulics as a branch of Engineering," by George Rennie, Civil Engineer. London, 1835.

The discharge of a stream is ascertained by multiplying its mean velocity by its area; and in gauging a river with this object in view, it is necessary, first, to determine accurately its sectional area in a plane as nearly as possible at right angles to the direction of the current, and immediately thereafter to make the observations for the measurement of its velocity before any change in the level and consequent alteration of the area obtained, has taken place.

A part of the river having been selected for this purpose, where the banks are regular and the stream tranquil, a graduated cord should be stretched across as nearly as possible at right angles to the direction of the current. The depths of water should then be carefully taken, with a rod graduated to feet and inches, or decimals, at every 5 or 10 feet (as indicated by the marks on the cord), according to the minuteness of the inquiry to be instituted, or the irregularity of the river's bed. This process being conducted in the same way as that already described at page 95, requires no further explanation. It seems only necessary to remark that the nature of this investigation renders an exact measurement of the breadth of greater importance than in the case referred to in Chap. VII., and that, as suggested by my friend Professor Gordon, a cord of brass wire, which, from its unyielding nature, would unquestionably form a more accurate measure, might be substituted with advantage for one made of hemp.

Having obtained an exact cross sectional area of the stream, the next point is to determine the velocity of the current passing through it. This, however, varies, gradually decreasing from the fair-way of the river towards the

sides, and from the surface towards the bottom; and therefore, for the purpose of calculation, the mean velocity must be determined. This is done by ascertaining the surface velocity in the middle of each of the compartments into which the transverse section of the river is divided, by the soundings made, as already explained, and from these surface velocities, by a simple formula, the mean velocity of each of the compartments can be obtained, and the mean of these will be the required mean velocity of the river.

For the purpose of ascertaining the surface velocities, various methods may be employed.

The most common, but by no means the most satisfactory, mode of proceeding, is to throw into the water a float composed of some small body (whose specific gravity is merely great enough to sink it to a level with the surface), at a point about 30 or 40 feet above the line of section, so as to insure its acquiring the full velocity of the current before it reaches the cord. An observer, stationed at the cord, notes exactly the moment at which the float passes, and follows it down the stream till he reaches the line of two poles, which have been fixed in reference to the observations, when he again notes the exact moment of its transit at the lower station. The elapsed time between the two transits is then noted in the book, along with the distance between the two places of observation, which, owing to the irregularity of most rivers, with regard to width, depth, and velocity, can seldom be got to exceed 100 feet. This operation has, of course, to be repeated for every compartment of the cross section.

Certain disadvantages attend this method, which render

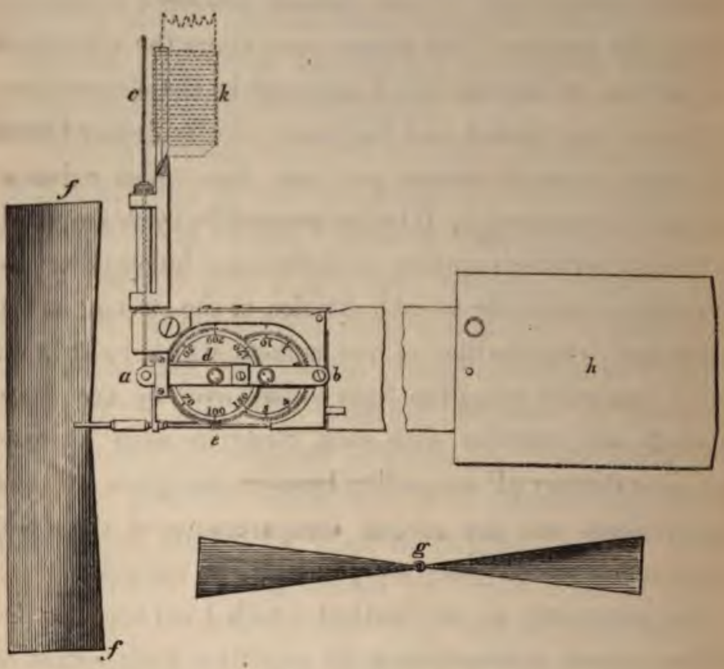
it not generally applicable. For example, it is only adapted to rivers of limited breadth, owing to the impossibility of an observer being able to discover with sufficient accuracy when the float passes the station lines, if it be viewed from a distance, as from the bank of a broad river. There are, however, greater objections than this, which, when pointed out, will be sufficiently obvious to every one. In any part of the river passed over by the floats, the slightest irregularity of the bottom produces a disturbance in the motion of the stream, and alters the velocity of the current, so that the result indicated by the elapsed time is more or less vitiated, and the mean velocity deduced from such data, is not, in almost any case, that which exists at the line of cross section. It is also impossible, by this method, to obtain a sufficient number of distinct and independent observations, applicable to each division of the stream, as the eddies and irregularities of the current which exist in all rivers, generally cause the lines passed over by the floats to cross and interfere with each other in such a manner as to destroy all connection between any given series of observations, and the several compartments of the river, whose mean velocity they were intended to ascertain.

The superiority of the method which I am about to describe, consists in ascertaining the velocity of each portion of the stream, in the exact line in which the cross sectional area is taken. The instrument employed for this purpose is a modification of the tachometer of Woltmann, which is in general use in France and Germany, both as an anemometer, and a hydrometer, being made of the degree of delicacy suited to the purpose to which it is to be applied. In this instrument

the velocity is measured by the current impinging on a vane and causing it to revolve, the number of revolutions made by the vane being registered on an index, which is acted on by a set of toothed wheels.

The construction of this beautiful instrument, and the manner in which it acts, will be best described by a reference to the accompanying cut, fig. 7., which is taken from

FIG. 7.



a tachometer or stream gauge made by Mr Robinson, optician, London, and is drawn to a scale of one third of the full size. In this view, *f f* represents what may be termed the driving vane, which is acted on by the stream, and of which *g* is a plan. The plane of this vane is twisted as represented by the dark shading in the cut, so as to present, not a knife-

edge, but an oblique face to the action of the current, which, by impinging on it, causes it to revolve exactly in the same way that the wind propels the sails of a windmill. On the spindle or shaft of this vane, an endless screw is fixed at *e*, which works in the teeth of the first registering wheel, and causes it to revolve, when the vane is in motion and the screw in gear. Letters *a* and *b* represent a bar of brass, to which the pivots on which the registering wheels revolve, are attached. This bar is moveable on a joint at *b*; and at the point *a*, a cord, *a c* is fixed, by pulling which the bar and wheels can be raised, and on releasing it they are again depressed by a spring at *d*. When the bar is raised, the teeth of the wheel are taken out of gear with the endless screw, and the vane is then left at liberty to revolve, the number of its revolutions being unregistered; but when the cord is released, the spring forces down the wheels, and immediately puts the registering train into gear, in which state it is represented in the cut. Letter *h* is a stationary vane (which is shewn broken off, but measures about 9 inches in length) for keeping the plane in which the driving vane revolves, at right angles to the direction of the current, and *k* is the end of a wooden rod to which the tachometer is attached when used. The different parts of the instrument itself are made of brass.

The moveable bar for the registering wheels and the application of the cord and spring which have been described, afford the means of observing with great accuracy in the following manner. The instrument having been adjusted by setting the registering wheels at zero, or noting in the field book the figure at which they stand, the cord is pulled

tight so as to raise them out of gear, and the instrument is then immersed in the water. The vane immediately begins to revolve from the action of the current, and is permitted to move freely round until it has attained the full velocity due to the stream. When this is supposed to be the case, a signal is given by the person who observes the time, and the registering wheels are at that moment thrown into gear by letting the cord slip. At the end of a minute another signal is given, when the cord is again drawn and the wheels taken out of gear, and on raising the instrument from the water, the number of revolutions in the elapsed time is read off. This operation being completed in the centre of each division of the cord, the number of revolutions due to the velocity at each part of the very line where the cross section is taken, is at once obtained.

Before using the tachometer, it is obvious that the value of a revolution of the vane must be ascertained; and although this is done by the manufacturers, it is proper that the scale of each instrument should be determined by the person who uses it, and that it be tested if the instrument has been out of use for some time, before being again employed in making observations. A scale sufficiently accurate for most hydrometrical purposes (though not for the instrument when used as an anemometer) may be obtained by applying it to some regular channel, such as a mill lead formed of masonry, timber, or iron, where the velocity is nearly the same throughout, and noting the number of revolutions performed during the passage of a float over a given number of feet, measured on the bank. In this way, it was found, by the mean of 62 observations, that each re-

volution of the vane in the instrument of which a drawing has been given, indicated the passage of the water over 46 inches. The number of revolutions at several parts of the stream was ascertained to be the same in equal times, at both the commencement and the end of the experiments. This number, therefore, becomes in the instrument alluded to, a constant multiplier of the number of revolutions indicated by the vane; and hence, the number of feet passed over by the water in the given interval of time is ascertained.

Having thus by means of the tachometer determined the surface velocity of the river at each of the divisions of the extended cord, the next step is the reduction of the observed surface to those of mean velocities, which will be readily done by the following rule of De Buat.

If unity be taken from the square root of the surface velocity expressed in inches, the square of the remainder is the velocity at the bottom, and the mean velocity is the half sum of these two.

Thus, let $\alpha =$ the observed surface velocity,

... $\beta =$ the bottom velocity, and

... $\gamma =$ the mean velocity.

$$\beta = \left(\sqrt{\alpha} - 1\right)^2 \text{ and } \gamma = \frac{\alpha + \beta}{2};$$

and hence, the mean velocity is directly deducible from the surface velocity by the following formula.

$$\gamma = \frac{\alpha + (\sqrt{\alpha} - 1)^2}{2}.$$

The following table of surface, bottom, and mean velocities may be useful in saving the trouble of calculation in cases where a great many observations have to be reduced.

TABLE OF SURFACE, BOTTOM, AND MEAN VELOCITIES.

Velocity in Inches.			Velocity in Inches.		
Surface.	Bottom.	Mean.	Surface.	Bottom.	Mean.
1	0.000	0.5	51	37.717	44.358
2	0.172	1.086	52	38.577	45.288
3	0.537	1.768	53	39.439	46 219
4	1.000	2.500	54	40.303	47.151
5	1.527	3.263	55	41.167	48.083
6	2.101	4.050	56	42.033	49.016
7	2.706	4.853	57	42.900	49.950
8	3.343	5.671	58	43.768	50.884
9	4.000	6.500	59	44.637	51.818
10	4.675	7.337	60	45.508	52.754
11	5.364	8.182	61	46.379	53.689
12	6.071	9.035	62	47.252	54.626
13	6.788	9.894	63	48.125	55.562
14	7.516	10.758	64	49.000	56.437
15	8.254	11.627	65	49.875	57.436
16	9.000	12.500	66	50.751	58.375
17	9.754	13.377	67	51.629	59 314
18	10.514	14.257	68	52.507	60.253
19	11.283	15.141	69	53.386	61.193
20	12.055	16.027	70	54.266	62.133
21	12.835	16.917	71	55.147	63.073
22	13.619	17.809	72	56.029	64.014
23	14.408	18.704	73	56.912	64.956
24	15.202	19.601	74	57.795	65.897
25	16.000	20.500	75	58.679	66.839
26	16.802	21.401	76	59.564	67.782
27	17.607	22.303	77	60.450	68.725
28	18.417	23.208	78	61.336	69.668
29	19.230	24.115	79	62.223	70.611
30	20.045	25.022	80	63.111	71.555
31	20.864	25.932	81	64.000	72.500
32	21.695	26.847	82	64.889	73.444
33	22.511	27.755	83	65.779	74.389
34	23.338	28.669	84	66.670	75.335
35	24.167	29.583	85	67.561	76.280
36	25.000	30.500	86	68.453	77.226
37	25.834	31.417	87	69.358	78.179
38	26.671	32.335	88	70.238	79.119
39	27.510	33.250	89	71.132	80.013
40	28.350	34.175	90	72.026	81.006
41	29.193	35.096	91	72.921	81.960
42	30.038	36.019	92	73.818	82.909
43	30.885	36.942	93	74.713	83.856
44	31.733	37.866	94	75.609	84.804
45	32.583	38.791	95	76.506	85.753
46	33.435	39.717	96	77.404	86.702
47	34.288	40.644	97	78.302	87.651
48	35.049	41.524	98	79.201	88.600
49	36.000	42.500	99	80.100	89.550
50	36.857	43.428	100	81.000	90.500

The mean velocities obtained, either by calculation or the use of tables, are to be multiplied into the area of the spaces in the centres of which the observations were made, in order to obtain the cubic contents of water discharged in each division; and to obtain the whole discharge, it is only necessary to add together the results of the observations made in all the different compartments. The apportioning of the stream into different parts, and treating each as a separate channel, appears to insure a much greater probability of a correct measurement than any method which depends upon assigning to the whole area a common velocity; and it is obvious that this method can be effectually followed only by the use of the tachometer described, or of some similar instrument (such as Pitot's tube), which possesses the advantage of confining its indications to the spot where the sectional area of the river is actually measured. Wherever, as will frequently happen in regular streams, the velocity of several compartments, as ascertained by the stream gauge, are found to be the same, the areas of these compartments may be added into one sum and multiplied by the common velocity. It seems necessary to observe that velocities exceeding 3 miles an hour are apt to injure an instrument of the size and proportions shewn in the cut, and that in gauging more rapid rivers, an instrument on the same principle, but of stronger make, should be employed.

Great convenience in this as in other departments of surveying and observing, will be found to result from registering all the observations in a tabular form. The following is an example of the observations made in ascertaining

the discharge of the River Conon in Rosshire on the 29th August 1837.

Plate XIII., fig. 3, is a sketch of the cross section made in the field book. The numbers marked horizontally on the level line are the distances; and those marked diagonally above it are the depths. The whole distance was divided into eleven compartments. The velocity of each was tried three times with the tachometer, their mean being taken as the correct velocity, and the following table contains the results of the calculations:—

No. of Section.	Surface Velocity per second in inches as observed.	Tabular Mean Velocity in inches.	Area of Section in square feet.	Discharge in cubic feet per second.
1	34	28.669	124.791	298.136
2	60	52.754	149.375	656.678
3	65	57.437	149.583	715.966
4	60	52.754	150.416	661.254
5	45	38.791	139.291	450.270
6	42	36.019	116.458	349.549
7	38	32.335	87.291	235.213
8	30	25.022	63.333	132.060
9	19	15.141	49.916	62.981
10	9	6.500	26.041	14.105
11	4	2.500	18.333	3.819
				3580.031 { Total Disch.

The velocity of currents in the open sea or in estuaries may be determined from a boat at anchor, by allowing a float to run out during a given interval of time, and observing the quantity of graduated line which has been let out.

Massey's log is also very suitable for such experiments; but it is not found to be well adapted for registering velocities much below 2 miles an hour.

It has occasionally been found interesting, if not absolutely indispensable, in certain inquiries which come before the civil engineer, to ascertain to what depth the currents penetrate, and whether under-currents exhibit the same phenomena in regard to direction and velocity as those of the surface. The tachometer of Woltmann, which has been already described, is the most convenient and accurate instrument that can be employed for depths of from 15 to 20 feet. I understand from Professor Gordon, that it is often employed in Germany for measuring velocities at much greater depths by the use of an apparatus erected on a platform supported on two boats.* But as its application under such circumstances may be regarded rather as a purely scientific than as an engineering experiment, it is not necessary to describe it in this place. The direction of the under current, which it is sometimes interesting to know, cannot, however, be obtained by means of the tachometer, and I shall describe a plan for obtaining an approximation to both the velocity and direction of under currents, which is of easy application, and may be useful to those employed in engineering investigations. The plan to which I allude was devised and used at the Cromarty Frith in 1837, by Mr Alan Stevenson, who discovered, by means of the instrument he employed, the interesting fact, that, at the depth

* Raucourt measured the velocity of the Neva at St Petersburgh with the tachometer at depths of 60 feet; Defontaine the Rhine at upwards of 40 feet; and Funk many rivers at depths of from 40 to 60 feet.

of 50 feet, the velocity of the current, at both flood and ebb, is in certain places of the Frith nearly double that at the surface. This instrument, which of course merely gave an approximate result, consisted (as shewn in the accompanying cut, fig. 8, at letter *a*) of a flat plate of sheet iron,

FIG. 8.

measuring 12 by 18 inches, having a vane made of the same material, and measuring 4 feet in length, fixed at right angles to the centre of it. The lower edges of the plate and vane were loaded with bars of iron, for the purpose of causing the instrument to sink to the requisite depth; and it was so slung as to preserve the surface of the plate in a vertical plane. This apparatus was secured by a cord of sufficient length to sink it to the required depth, and the whole was attached to a tin buoy, letter *b*, which floated on the surface, its form being such as to produce little resistance to its passage through the water. The buoy served not only to preserve the vane plate at the same depth, but also indicated its progress through the water in a very satisfactory and often interesting manner.

The plate, sunk at the depth of 50 feet, when acted upon by the force of a strong under current, was hurried along,

carrying the buoy, which floated on the surface, along with it, a circumstance which was ascertained by the buoy passing the floats thrown out on the water as gauges of the velocity and direction of the upper current, one of which is shewn at *c*. The only precaution to be observed in making such observations, is to exclude that part of the commencement of the buoy's course, which is more rapid than it ought to be, owing to the effort made by it to overtake the plate, which, being sunk first, has been influenced by the velocity of the under current before the buoy has been launched. It is evident that, by means of this simple apparatus, we can approximate to the direction as well as to the velocity of under currents; but it must be kept in view that, in either case, there are several deranging influences in operation, which tend to render the results obtained merely rude approximations to the truth.

The direction of surface currents may be easily observed by means of a string of cork floats. Any change in the direction of the line traced by the floats is noted by observations made with the surveying compass or the sextant, by an observer stationed in a boat, which is rowed alongside of the line marked out.

The last hydrometrical topic which shall engage our attention, is the method of obtaining specimens of water at different depths, with a view to ascertain its qualities in regard to the proportion of sea salt which it contains, or the quantity of sand or mud held in mechanical suspension.

The first observations made on this subject, so far as I am aware, were those instituted by my father on the River Dee in Aberdeenshire, in the summer of the year

1812, when engaged in surveying that river in reference to a salmon fishing case.* "He observed in the course of his survey that the current of the river continued to flow towards the sea with as much apparent velocity during flood as during ebb tide, while the surface of the river rose and fell in a regular manner with the waters of the ocean. He was led from these observations to enquire more particularly into this phenomenon, and he accordingly had an apparatus prepared, under his directions, at Aberdeen, which, in the most satisfactory manner, shewed the existence of two distinct layers or strata of water; the lower stratum consisting of salt or sea water, and the upper one of the fresh water of the river, which, from its specific gravity being less, floated on the top during the whole of flood as well as ebb tide. The apparatus consisted of a bottle or glass jar, the mouth of which measured about 2½ inches in diameter, and was carefully stopped with a wooden plug, and luted with wax; a hole, about half an inch in diameter, was then bored in the plug, and to this an iron peg was fitted. To prevent accident in the event of the jar touching the bottom, it was coated with flannel. The jar so prepared was fixed to a spar of timber about 20 feet in length, which was graduated to feet and inches, for the conveniency of readily ascertaining the depths to which the instrument was plunged, and from which the water was brought up. A small cord was attached to the iron pin for the purpose of drawing it at pleasure for the admission of the water. When an experi-

* Report to the Earl of Aberdeen and the other proprietors of the "Raik" and "Stell" fishings of the river Dee, at Aberdeen, by Robert Stevenson, Civil Engineer. Edinburgh, Feb. 1813.

ment was made, the bottle was plunged into the water; by drawing the cord at any depth within the range of the rod to which it was attached, the iron peg was lifted or drawn, and the bottle was by this means filled with water. The peg was again dropped into its place, and the apparatus raised to the surface, containing a specimen of water, of the quality at the depth to which it was plunged. In this manner, the reporter ascertained that the salt, or tidal water of the ocean flowed up the channel of the River Dee, and also up Footdee and Torryburn, in a distinct stratum next the bottom and under the fresh water of the river, which, owing to the specific gravity being less, floated upon it, continuing perfectly fresh and flowing in its usual course towards the sea, the only change discoverable being in its level, which was raised by the salt water forcing its way under it. The tidal water so forced up continued salt, and when the specific gravities of specimens from the bottom, obtained in the manner described, were tried, and compared with those taken at the surface, by means of the common hydrometer of the brewer (the only instrument to which the reporter had access at the time), the lower stratum when compared with that at the surface was always found to possess the greater degree of specific gravity due to salt over fresh water."

The appearance of the fresh water floating on the surface of the sea, is no doubt familiar to most persons. It occurs at the mouths of many of our rivers, and is most apparent when they are in flood, from the brown tinge given to the water, which is easily discoverable for many miles at sea. The great American rivers furnish many remarkable instances of this, particularly the Amazons and La Plata. On this

subject, the following passage from the work* of Father Manuel Rodriguez, a Spanish Jesuit, is interesting, and its correctness as regards the extent to which the influence of these rivers is felt, has since been corroborated by the investigations of Colonel Sabine.† "This river," says Rodriguez, in speaking of the Amazons, "is like a tree, its roots enter as far into the sea as into the land. It communicates to it a flavour; so that at 80 leagues within the sea, its waters are seen and taste sweet, and in a semicircle of 100 leagues in circumference, they form a gulph not in the least degree brackish, so that the sailors call it the fresh sea."

The instruments now used for obtaining water from different depths, are more perfect in their construction than that already alluded to as having been used at the Dee, which, as has been seen, was made for a temporary purpose. Instruments of various constructions have of late been tried for experimenting on this subject by Scoresby, Sabine, and others; and as I am not aware that any work on marine surveying, or on surveying instruments, contains a description of such an apparatus (to which I have applied the name of the *hydrophore*‡), the following account of two modifications of it, both of which I have been in the habit of using, may perhaps be instructive.

Fig. 9. represents a hydrophore used for procuring specimens of water from moderate depths, drawn on a scale of one tenth of the full size. It consists of a tight tin cylinder, letter *a*, having a conical valve in its top *b*, which

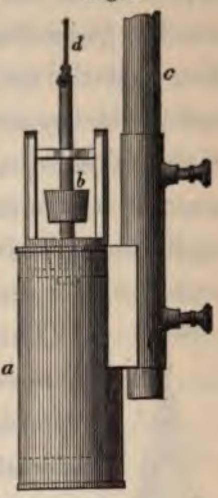
* El Marañam y Amazonas. Madrid, 1684, p. 18.

† An Account of Experiments to determine the figure of the Earth, as well as on various other subjects of philosophical inquiry, by Edward Sabine. London, 1825, p. 445.

‡ ὕδωρ and φορέω.

is represented in the diagram as being raised for the admission of water. The valve is fixed *dead*, or immovable, on a rod working in guides, the one resting between two uprights of brass above the cylinder, and the other in its interior, as shewn in faintly dotted lines. The valve-rod is by this means caused to move in a truly vertical line, and the valve attached to it consequently fills or closes the hole in the top of the cylinder with greater accuracy than if its motion was undirected. A graduated pole or rod of iron *c*, which, in the diagram is shewn broken off, is attached to the instrument, its end being inserted into the small tin cylinder at the side of the large valve or water cylinder, and there fixed by the clamp screws shewn in the diagram; the bottom of the water cylinder may be loaded with lead to any extent required, for the purpose of causing the apparatus to sink; but this, when an iron rod is used for lowering it, is hardly necessary. The spindle carrying the valve has an eye in its upper extremity, to which a cord is attached for the purpose of opening the valve when the water is to be admitted, and on releasing the cord, it again closes by its own weight. When the hydrophore is to be used, it is lowered to the required depth by the pole which is fixed to its side, or if the depth be greater than the range of the pole, it is loaded with weights and let down by means of a rope so attached as to keep it in a vertical position. Care must be taken while lowering or raising it, that the small cord by which the valve is opened be allowed to hang perfectly free and slack. When the appa-

Fig. 9.



ratus has been lowered as far as is required, the small cord is pulled, and the vessel is immediately filled with the water which is to be found at that depth. The cord being then thrown slack, the valve descends and closes the opening, and the instrument is slowly raised to the surface by means of the rod or rope, as the case may be, care being taken to preserve it in a vertical position. This apparatus is only applicable to limited depths, but will generally be found to answer all the purposes of the civil engineer.

Fig. 10.

The form of hydrophore represented in fig. 10 is used in deep water, to which the small one just described is inapplicable. It consists of an egg shaped vessel, letter *a*, made of thick lead, to give the apparatus weight, having two valves *b* and *c*, one in the top and another in the bottom, both opening upwards; these valves (which are represented as open in the diagram) are, to ensure more perfect fitting, fixed on separate spindles, which work in guides, in the same manner as in the instrument shewn in fig. 9. The valves, however, in the instrument I am now describing, are not opened by means of a cord, but by the impact of the projecting part *d*, of the lower spindle on the bottom, when the hydrophore is sunk to that depth. By this means the lower valve is forced upwards, and the upper spindle (the lower extremity of which is made nearly to touch the upper extremity of the lower one, when the valves are shut) is at the same time forced up, carrying along with it the upper valve which allows the air to escape, and the water rushing in fills the vessel. On raising the instrument from the bottom,

both valves again shut by their own weight and that of the mass of lead *d*, which forms part of the lower spindle. The mode of using this hydrophore is sufficiently obvious; it is lowered by means of a rope, made fast to a ring at the top, as shewn in fig. 10, until it strikes on the bottom, when the valves are opened in the manner described, and the vessel is filled; on raising it the valves close, and the vessel can be drawn to the surface without its contents being mixed with the superincumbent water through which it has to pass. This instrument weighs about half a hundred weight, and has been easily used in from 30 to 40 fathoms water in making engineering surveys, and could no doubt be employed for much greater depths if necessary. It is represented in the cut on a scale of one-twentieth of the full size.

In all these experiments, the water being emptied into bottles, is corked up, sealed, and labelled with certain numbers, which should be entered in a book containing remarks as to the place of observation, time of tide, and such other particulars as, from the nature of the inquiry, seem to deserve notice, and the water thus preserved may be subjected to analysis, produced in evidence, or employed in any other way required by the circumstances of the case.

The marine productions of an estuary, such as the fish, shells, and plants which occur in it, occasionally affect questions regarding which an engineer may be consulted; but as it is not my present intention, as stated at the beginning of this Chapter, to enter into the nature of the questions in which such investigations are required, or the manner in which they bear upon them, it is not considered necessary, in mentioning these productions, to do more than simply direct attention to the subject.

CHAPTER IX.

PROTRACTION OF THE TRIANGULATION, BASE LINE AND TRAVERSE SURVEY.

Methods of protracting triangulation—By the calculated sides of the triangles—By the bearings—Principle on which protraction by the bearings is based—Protractors used—Drawing protractor on the paper—Method of dividing it—Method of transferring bearings to different parts of the paper—Protraction of base line, *first*, When it lies between two triangulation stations; *second*, When it does not extend between triangulation stations, but is nevertheless connected with the triangulation by bearings; *third*, When the base is not connected with the triangulation—Trigonometrical calculation for solving third case—Method of protracting triangulation before laying down base line—Objections to this mode—Correction of the measured length of the base necessary—Protraction of the survey of the high water margin when the system of chain or traverse surveying is employed—Checking accuracy of the measurement of the survey lines.

Protraction may be defined as that process whereby the data obtained during a survey are transferred to paper and recorded for the use of the engineer. Being conducted entirely in the office, it is termed "house" or "office work," to distinguish it from the operations treated of in the foregoing chapters, all of which are performed in the field.

It has been already shewn, that these field operations are the groundwork of the opinions, designs, and estimates, of

engineers; and as it is only when represented on a plan that they can be advantageously applied to such practical purposes, the most accurate means of protracting them is obviously a subject of no less importance than that of conducting the survey itself, and to its consideration, therefore, the remaining chapters will be devoted.

In treating of the field work, it was thought advisable, in order to simplify the subject, to devote separate chapters to the consideration of the triangulation, the selection and measurement of the base line, and the survey of the high water margin of the river; but in describing the protraction of these different departments, it will be more convenient to include the whole of them in the same chapter.

The method of protracting the triangulation by calculating the distances between the different stations and laying down their positions by measurement, is perhaps better adapted than any other process to extensive surveys in which great accuracy is required. In almost all engineering surveys, however, the positions of the triangulation stations may be determined with sufficient accuracy by the intersections of the bearings taken in the field, when laid down in the manner hereafter described, and this system should be adopted in preference to the other in all cases where it is practicable to do so, laborious trigonometrical calculations being thereby avoided, and greater convenience afforded for laying down the traverse survey. To it, therefore, I shall confine my remarks.

It may be stated in the outset, that, in the mode of protracting about to be described, the principle on which the bearings are laid down is the same as that on which the

field work of the survey is conducted, and is based on the parallelism of the same bearings at all the different stations, which has already been fully explained in Chapter I., and is illustrated in Plate II.

The accuracy of the plan or chart to be constructed may be said to depend, in a great measure, on the correctness of the triangulation, and the whole of this important department should, if possible, be protracted before the completion of the survey, or, at all events, before the surveyors leave the neighbourhood, so that if any error has been committed, an opportunity may be afforded of rectifying it by revising the field work. It is therefore of much consequence to be possessed of some simple, and at the same time efficient means, for accomplishing this desirable object. Many protractors of different forms and materials have been constructed, most of which are useful for the peculiar purposes for which they were more especially intended; but I have never met with any portable protracting instrument which seemed at all well adapted for laying down the bearings of a trigonometrical survey of even moderate extent.

The method which I have invariably found to be most convenient, and at the same time best fitted for effecting this operation, is to draw the protractor on the sheet of paper on which the survey is to be laid down; or, in other words, to describe on it a circle of 12 or 14 inches in diameter, and to divide it into 360 equal parts. The graduation requires to be done with great care, and a little time is occupied in executing it; but if an accurately divided circle, or even a semicircle of brass or card, be employed for the

purpose, the process is greatly simplified, and much time and trouble saved. The graduated circle is placed on the spot to be occupied by the protractor, and the degrees carefully pricked off on the sheet of paper, an operation which may be performed in a very few minutes. In most cases, it is necessary, as will be shewn more particularly hereafter, to draw several of these protractors on the paper, their number varying according to the size of the plan to be made; and it therefore becomes an object of importance, when much surveying of this kind is to be done, to have a graduated instrument constructed for laying down the circles in the manner described.

Sheets of paper having protractors engraved on them are also used for extensive surveys; but an objection has been raised to this method, as the process of printing the impression of the plate is said to injure the paper for drawing. I am not aware, however, whether this objection be founded on good grounds, as I have never employed protractors of this description. I believe that, in the practice of most engineers, the method of pricking off the circle on the sheet will be found fully to answer every purpose.

If a graduated circle be not used for laying down the protractor, the following neat method of performing the division, which is recommended by Mr Simms, may be adopted.*

"The great difficulty," says Mr Simms, "of dividing a circle accurately, is well known, but if the arcs are laid off by means of their chords, the division may be performed

* A Treatise on the Principal Mathematical Instruments employed in Surveying, Levelling, and Astronomy, by Frederick M. Simms, p. 93. London, 1834.

with sufficient exactness for the purpose in hand. The lengths of the chords should be taken from an accurately divided beam compass, which, to ensure success, should be set with the utmost possible exactness.

"With a radius of 5 inches describe a circle, and immediately, without altering the compasses, step round the circle, making a fine but distinct mark at each step; this will divide the circle into six parts of 60° each.

"Next set the compasses to the natural sine of 15°, which to radius five will be equal to the chord of 30°" (the radius of the tables of natural sines being 10), "and this distance will bisect each 60°, and divide the circle into arcs of 30° each. A proof may be obtained of the accuracy of the work as it proceeds, by setting the succeeding chords off each way from those points which they are intended to bisect; for if any inaccuracy exists, the bisection will not be perfect, and if the error proves inconsiderable, the middle point may be assumed as correct.

"Each sixty degrees may next be trisected by setting off the natural sine of 10° (equal to the chord of 20° to our radius), which will divide the circle to every ten degrees.

"Next the natural sine of 7° 30′ (equal to the chord of 15°) stepped from the points already determined, will divide the circle to every fifth degree.

"The natural sine of 3° (equal to the chord of 6°) being laid off, divides 30° into five parts, and, set off from the other divisions, divides the circle to single degrees.

"Fifteen degrees bisected or the natural sine of 3° 45′ (equal to the chord of 7° 30′) set off from the other divisions, divides the circle into half degrees.

"The natural sine of 3° 20′ (equal to the chord of 6° 40′) divides 20° into three parts, and, set off from the rest of the divisions, divides the whole circle to every ten minutes, which is as minute a subdivision as such a circle will possibly admit of; smaller quantities must therefore be estimated by the eye."

This method of dividing refers to a circle of 10 inches in diameter, which, in some cases, will be found to be rather too small, but if one of 20 inches be adopted, which for large surveys is a very convenient size, the same steps may be taken for graduating it, the natural sines of the whole, instead of half the angles, being laid off.

In Plate I., which represents part of the river Tay drawn on a scale of about one fifth of that on which the work was originally protracted, two of the plotting circles are shewn.

In laying down these circles, care should be taken that the bearing coinciding with the direction of the greatest extent of the survey (which, in most cases, can be approximately ascertained with ease) be placed so as to coincide with the greatest axis of the sheet of paper. Thus, in the case of a survey, where the river lies due north and south, the bearing of 360° should be placed in the direction of the greatest axis of the paper; or if the river lies east and west, the bearing, 90°, should be made to coincide with it. If this precaution as to the coincidence of the greatest limits of the survey with those of the sheet on which it is to be protracted be not attended to, the work may, as the protraction proceeds, run off the paper long before it has been filled, a circumstance which is attended with great inconvenience.

In treating of the measurement of the base line, it will

be remembered that three cases were alluded to, in all of which the observations for fixing its extremities were conducted on somewhat different principles; and as the methods by which they are protracted also differ, each case must be explained separately. In proceeding to shew in what way the triangulation of the survey is to be laid down, I shall, in the first instance, advert to those cases in which the base line has been measured between two of the triangulation stations, the method which was recommended to be adopted wherever it is at all practicable.

Before laying off any of the bearings, the scale (in the proportion of a certain number of inches to the mile) on which the plan is to be made, ought to be determined and laid down on the paper. The size of what is called the rough plan should, for facilitating the protraction, be as large as is consistent with convenience, especially as it may be afterwards accurately and easily reduced, by means of the eidograph, to any scale that may be required.

When the scale has been drawn in, the bearing of the two base line stations must be ascertained by referring to the field book, and the corresponding bearing on the protracting circle having been transferred to the part of the paper on which the base line is to be placed, a pencil line should be drawn to represent its direction.

On the principle of the parallelism of the same bearings at all the stations, it is necessary to be able to transfer them from the circle to any part of the paper without altering their relative directions in reference to the divisions of the circle itself. This may be done either by means of a pair of large parallel rulers, or by a T square moved along a

straight edge. In either case, the straight line formed by one of the edges of the apparatus employed for the purpose is made to coincide on the circle, with the bearing which is to be laid down. The square or the rulers, as the case may be, are then moved to the part of the paper on which the bearing is to be drawn, care being taken not to disturb the parallelism of the straight edge to the line of bearing to which it had previously been adjusted.

When this bearing has been protracted, the length of the base, as measured on the ground, must be carefully taken from the scale of distances attached to the plan, and pricked off on the line of bearing which has been drawn on the paper. It is evident that the positions of two of the triangulation stations, in reference to both the scale and the protracting circle, have been fixed on the plan by this process. These stations, for the sake of rendering further explanation more clear, we shall call A and B. The angles taken from A to the several stations C, D, E, &c., are next to be laid down, the whole of them being carefully transferred from the circle to the point A, from which they were observed, and drawn in on the plan in pencil lines. The same operation is to be gone through at station B. Now, if the work is accurate, the points at which the bearings laid off from A and B to the different stations intersect each other, will be the positions of these stations on the plan. Their positions cannot, however, be finally determined without a third bearing, as a check on the intersection of the other two; and for this purpose some one of the stations, which we may suppose to be C (whose position has, if we may use the expression, been temporarily fixed

by the intersection of the two bearings laid off from A and B), must be assumed as correct. It must be remembered, however, in making choice of the third station C, that, in all cases where the angle made by the two bearings at the point of their intersection is either very acute or very obtuse, the accuracy of the position of the station so fixed is not to be relied on, and one should therefore be selected at which the bearings for its determination include as nearly as possible 90 degrees, the angle which forms the most favourable intersection. As a further precaution in assuming the point C, it is proper, by reference to the field book, to ascertain whether the observed angles included in the triangle A B C, formed by the three stations, be equal, or very nearly equal, to 180°. If this proves to be the case, it may be inferred that the angles A B C, B A C, and A C B have been accurately observed and noted in the field book; and the point C may, if the intersection be good, be safely adopted as the third station. When the third station C has been assumed, the bearings taken from it should be laid off, and drawn in pencil lines; and if the work be correct, these lines will exactly intersect the points of intersection of the several bearings from A and B before protracted, thus proving the accuracy of points whose positions have been determined by them. Any of the points whose positions have been thus fixed by the coincidence of three bearings may now be chosen from which to protract the angles, and in this way the whole triangulation is laid down, the positions of many of the stations being fixed by the intersection of eight or ten bearings from different points, a result which is always satisfactory.

It is necessary to remark, that, whenever the distance between the protracting circle and the stations to be laid down becomes so great as to occasion inconvenience and loss of time, and create the chance of committing errors in transferring the bearings, another circle, as represented in Plate I., should be drawn on the plan, from which the bearings can be transferred in the manner already described. It is indispensable, however, that the bearings of the second circle be made parallel to the corresponding bearings of the original one; and if this be strictly adhered to in every case, any number of circles may be employed in the protraction, according to the size of the plan.

Plate I. illustrates the process which I have attempted to explain. The lines joining the different stations represent the bearings taken in the field, and correspond with those of the same name on the circles. Thus, in the example of the field book given at page 15, the bearing from Balmerino to Invergowrie station is noted as being 189° 34′ on vernier A, and 9° 34′ on vernier B; and the line on the plate joining these two stations will be found to correspond in parallelism with that which passes through the divisions, 189° 34′ and 9° 34′ on each of the two protracting circles shewn; and so with all the other lines drawn on the plan.

The bearings laid down, in the manner described, being the same as those taken in the field, and the length of the protracted base being made to agree (with reference to the scale which has been determined on) with the distance measured on the ground; it is obvious, on the principles on which trigonometrical calculation is founded, that the distances be-

tween the different stations, when measured by the same scale, will agree with those distances when measured on the ground, or, in other words, that the plan constructed will (if the work has been accurately executed) exhibit a correct representation of the relative positions of the several stations on the banks of the river. The accuracy of the protraction may be tested by means of a base of verification, which is obtained by calculating from the data procured in the field, the length of the line joining any two stations of the survey between which the distance is considerable; and if this calculated length be found *nearly to agree* with the distance on the plan measured by the scale, the survey may be considered as having been accurately protracted. I use the expression *nearly to agree*, because (as must have been all along perceived) I am treating of a mode of working adapted to the ordinary practice of civil engineering. It must be recollected that, in the system I have described, the angles are read off only to minutes. The refinement of calculating the sides of the triangles and protracting by measurement from a scale, as well as that of making an allowance for the unequal expansion and contraction of the drawing paper produced by changes in the hygrometric state of the air, although indispensable for some purposes, are not in the present case taken into account. The nearness of the agreement between the calculated and measured distances ought therefore to be estimated by the degree of refinement that has been gone into in surveying and protracting the work, and is a point which must be left to the judgment of the engineer, whose knowledge of the object of the

survey and the whole bearings of the case, will enable him to decide.

I must now proceed to explain the method of connecting the measured base with the triangulation in cases where the line does not extend between two of the triangulation stations.

When the line is measured on a marsh or a sand bank, in the manner explained in Chapter II., and the bearings taken at its extremities are referred, by means of a back sight, to the triangulation of the survey, the method of procedure is sufficiently obvious and simple, for the bearing of the base line being known, its site may be laid down from the protracting circle. Its length, as measured on the ground, is then pricked off on the bearing which has been drawn on the paper, and the extremities of the line become the starting stations of the triangulation, the angles taken from them being protracted in the manner already described.

The process of protracting the third case, however, is not so simple as either of the two I have explained. In that case, it was supposed that the base line was measured on a sand bank, and that angles were taken from its extremities to the surrounding stations of the triangulation, in order to fix its position; but it was further supposed, that, owing to certain circumstances, it was impossible to make an observation from any of the stations in the triangulation to either of the extremities of the base line. In order to protract the work, it is necessary, from the data obtained by measuring the base, and observing at its extremities the angles subtended by the surrounding stations, to calculate the distance

between any two of them, and assume that distance as the first line of the protraction.

The case may assume either of the two forms represented in figs. 11 and 12, in which A B represents the base line, and D and C two of the triangulation stations, the distance between which is required. In fig. 11, the angles, from the extremities of the base line, are supposed to be taken to two stations which are on the same side of the river; and in fig. 12, the angles are taken to stations on opposite sides of the river. The same trigonometrical calculation, however, applies to both, and is as follows:—

Fig. 11.

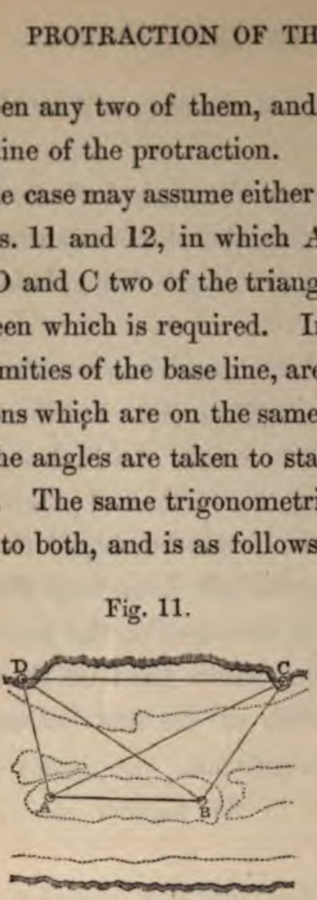
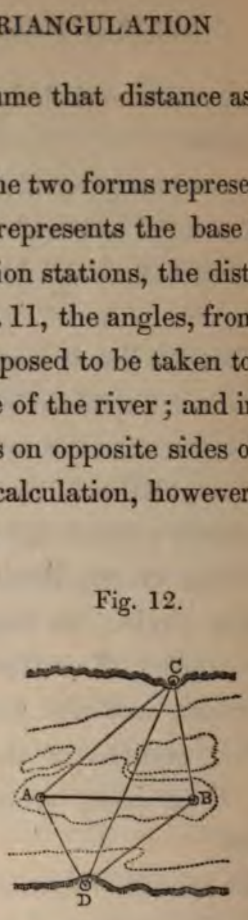


Fig. 12.



Let A B in either of the figures be the measured base line.

From the point A observe the angles D A B, B A C, C A D, and from the point B observe the angles A B C, A B D, D B C.*

Then in the triangle A C B

$$A\,C = \frac{A\,B \times \sin A\,B\,C}{\sin A\,C\,B};$$

* It is proper, in practice, to observe the sum of the two angles, as a check on their accuracy.

and in the triangle A D B

$$A\,D = \frac{A\,B \times \sin D\,B\,A}{\sin A\,D\,B}.$$

Now, in the triangle A D C, we know D A and A C, and the included angle D A C, and consequently the sum of the angles A D C and A C D, which is supplementary to D A C.

But

$$\tan \tfrac{1}{2}(A\,D\,C - A\,C\,D) = \frac{\tan \frac{1}{2}(A\,D\,C + A\,C\,D) \times (A\,C - D\,A)}{(D\,A + A\,C)},$$

and therefore the greater angle

$$A\,D\,C = \tfrac{1}{2}(A\,D\,C - A\,C\,D) + \tfrac{1}{2}(A\,D\,C + A\,C\,D),$$

and the less angle

$$A\,C\,D = \tfrac{1}{2}(A\,D\,C + A\,C\,D) - \tfrac{1}{2}(A\,D\,C - A\,C\,D),$$

and $$C\,D = \frac{\sin D\,A\,C \times A\,C}{\sin A\,D\,C};$$

or $$C\,D = \frac{\sin D\,A\,C \times A\,D}{\sin A\,C\,D}.$$

The bearing of the line C D is then to be laid down, and its calculated length being pricked off, the points C and D become the starting points from which the observed angles are to be protracted in the manner already described.

Before leaving the subject, it is necessary to remark, that the whole of the triangulation may be protracted before the base line is laid down, the distance between the two starting stations being assumed without reference to any scale. In proceeding in this way (which is not by any means generally recommended, though it may be occasionally useful and convenient), the site of the base line is fixed on the plan after the whole or a part of the triangulation is laid down, and the distance determined by the protraction of the angles fix-

ing its extremities is assumed as the scale to the plan. Thus, if the length of the base measured were 8000 feet, the protracted line would represent that distance on the plan, and be divided accordingly for a scale. Hence the necessity, if this mode of protracting be adopted, of making the length of the base line an easily divisible quantity, as noticed at page 27; for if, instead of 8000, the distance were 8007 feet, it would be difficult to divide the line accurately in terms of the latter quantity. The greatest disadvantage which attends the practice of laying down the triangulation before the base line, consists in the difficulty, if not the impossibility, of constructing the plan so protracted according to any definite scale, as eight, ten, or twelve inches to the mile, which it is in all cases advisable to do. It will readily be perceived in what way this difficulty arises. In the one case, the scale of the plan is, in the first instance, adopted at the rate of any number of inches to the mile, and from this scale the length of the base line is laid down; but, in the other case, the plan may be said to be constructed before the scale is formed, the length of the base line being determined by the protraction of the bearings which fix its extremities, and hence there is only a chance, and that a very remote one indeed, that its protracted, will bear to its measured length the exact ratio of any number of inches to one mile.

If a land surveyor has been employed to survey the margin of the river, he ought to be furnished with a skeleton plan shewing the positions of all the triangulation stations, on which to protract the several compartments of the survey extending between them. The fixed points on this

skeleton plan serve as checks on the correctness of the work, and as guides for the directions of the measured lines; while the division of the survey into compartments, as already noticed, prevents the accumulation of error. As the engineer, however, may in some cases be obliged to execute this part of the work by traverse surveying, in the manner described in Chapter VI., I shall explain the method of protracting the survey when made in this manner.

The bearings of the different station lines, as already noticed in explaining the system of traverse surveying, are connected with those of the triangulation by starting from one of the triangulation stations, and taking back bearings throughout the whole of the survey. It is evident, therefore, that the method of protraction used for the triangulation will answer equally well for laying down the lines of the traverse survey. The bearing of the first line of the survey ought to be laid off, by means of the protracting circle, from the triangulation station at which the survey was commenced. The measured distance of the survey line must then be taken from the scale, and pricked off on the bearing laid down, the extremity of the line thus fixed, being the point from which the bearing of the second line is to be laid off. The bearings and lengths of all the lines are successively protracted in this manner, until the last line of the compartment is reached; and if the work be right, the extremity of this line should, of course, coincide with the position of the station, as fixed on the plan at which the compartment was made to terminate. This process will be clearly understood by the example given in Plate I., on which, in order to illustrate the subject, the survey lines between Flisk and Birkhill stations have been

laid down. The small circles along the shore represent the stations at the extremities of the different lines.

If the extremity of the last survey line do not coincide with the triangulation station, some error has been committed, either in the field work or in the protraction. If the work on revisal is found to have been correctly protracted, the accuracy of the positions of the different survey stations at the extremities of the lines should be tested, by laying off at each of them, the bearings taken during the survey to the different triangulation stations. By this means it will generally be discovered that the position of some one of the survey stations is erroneous; and in most cases it happens that the amount of error is exactly 100 feet, proving a faulty measurement, owing to some error in changing or counting the number of the marking pins. On examining the field book, the part of the line at which the error occurred can generally be detected. After correcting this error, and reprotracting the lines, the extremity of the survey will be found exactly to coincide with the station, if no other error exists in the work. The benefits arising from dividing the survey into compartments, and taking bearings at each of the survey stations to all the triangulation stations within view, as explained in Chap. VI., is thus very apparent.

When the whole of the lines have been laid down and verified in the manner described, the measurements of the lengths and offsets are then to be protracted,* and the outline of the ground, as represented in the field book, carefully traced in.

* A plotting offset scale, as recommended by Mr Simms, will be found very convenient for this purpose.

CHAPTER X.

PROTRACTION OF LOW WATER SURVEY AND SOUNDINGS.

Protracting sextant observations for fixing positions of points—The station pointer—Protracting them by construction—Ordinary rule for this—Improved method—Solution of the problem on which the method is based—Practical application of the principle—Objections to protracting by construction—Protracting the outlines of low water channel and sand banks—Protraction of soundings—High water soundings—Low water soundings—Formulæ for ascertaining the rise of tide and the heights of the sand banks above low water—Method of protracting a longitudinal section.

Before entering particularly on certain details which have still to be noticed with reference to laying down the soundings and sand banks, it seems necessary to offer a few remarks regarding the protraction of the sextant observations, made in the manner described in Chap. V, for the purpose of determining their positions. The most convenient method of doing this, is by using the instrument called the Sta-

tion Pointer. The construction and the mode of applying that instrument, are fully described in Mr Simms' treatise, to which I have had occasion already to refer, and it is therefore unnecessary to enter on the subject here.

As it may occasionally happen, however, that access cannot be had to a station pointer, or that the points to be laid down are so near the stations observed, or the scale of the plan is so small as altogether to preclude the use of the instrument, the surveyor should not be unprovided with the means of protracting his work without its aid.

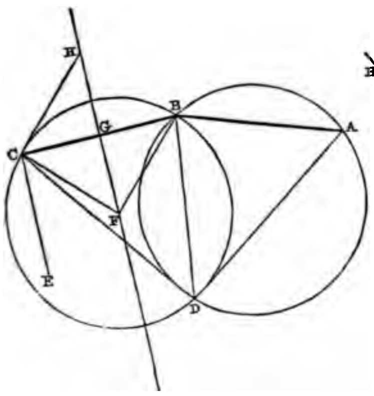
The rule generally given for protracting the work in such cases, is as follows :—*Subtract double the observed angle from* 180°, *and from the two stations observed, draw straight lines making angles with the line joining them, each equal to half the remaining angle. The point at which the lines so laid off intersect each other, will be the centre of a circle passing through the observed stations, and the point from which the observations was made.* But as this is a tedious operation, and the rule does not apply to every case, I shall take the liberty of describing a simple and efficient method of protraction, of which, when necessary, I invariably avail myself. I have never met with a description of this method in any work on the subject, and first saw it employed by the late Mr James Ritson of Edinburgh.

In order, however, that the system of protracting about to be described may be easily understood, it is necessary that the reader should know the principles on which it is based, and these will probably be best explained by giving the solution of the following problem.

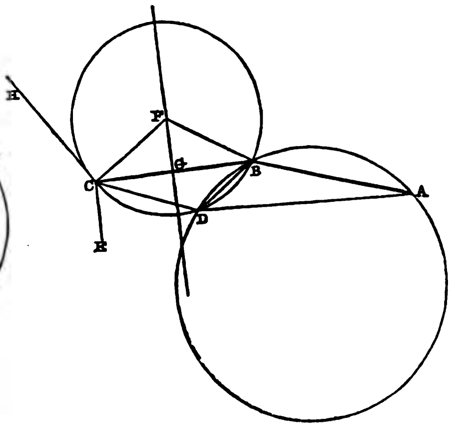
Given the positions of three objects, and also the angles

which they subtend at a station in their plane, to find the position of the station.

13.



14.



Let A, B, C, (figs. 13 and 14) be three objects whose positions are known, and which subtend at D, the point of observation, two known angles A D B, B D C; it is required to determine the position of the point D.

Through C draw C E perpendicular to C B, and make the angle E C F equal to the observed angle B D C. Bisect B C in G, and draw G F perpendicular to B C and meeting C F in F. From the point F with the radius F C, describe the circle B C D; the point D will be found in its circumference. By a similar construction in reference to the angle B D A subtending the line B A, a circle A B D may be described, passing through the point D, and the point at which the circles C D B and A D B intersect each other, is the point of observation required.

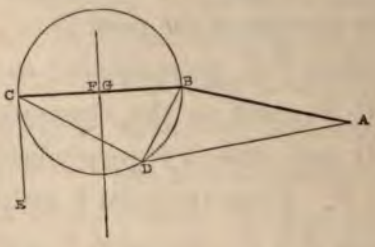
For, join F B, D C, and D B, and draw C H perpendicular to F C.

Now, since E C G = F C H, each being a right angle, and F C G being common to both, E C F = G C H.

But F B = F C (Euclid B. I, p. 4); and the point B is in the circumference of the circle B D C (Euc. I Def. 15); and the line C B cuts it (Euc. III. 2); and since C B cuts the circle C B D, and C H touches it (Euc. III. 18), then (Euc. III. 33) G C H = C D B, the angle in the alternate segment. But G C H = E C F, and E C F by construction = the observed angle ∴ C D B in the segment of the circle C D B = the observed angle. In the same way, it may be shewn that the angle A D B in the segment of the circle A D B = the observed angle, and (Euc. III. 21) the point D must be that from which the observations were made.

It will be observed that the foregoing proof refers to the two cases where the observed angle is either above or below

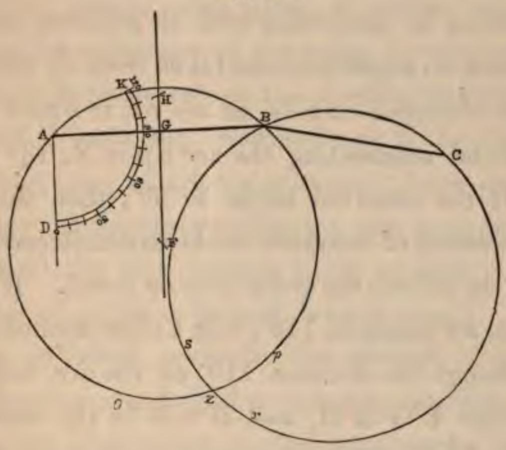
Fig. 15.



90°. When the observed angle C D B, as in fig. 15, is a right angle, the line C F will evidently coincide with C B, and the point F, with the point G; and F, being the centre of the circle B D C and F C the radius, the line C B will be the diameter, and (Euc. III., 31) C D B will be equal to 90° the angle observed.

Now, in order to apply the principles demonstrated to practice, a little construction only is required; and I have in the following diagram (fig. 16) shewn how this may be done.

Fig. 16.



Let A and B be two stations to which we shall suppose many observations for laying down the positions of the banks and soundings have been taken. Join A B, bisect the line in G, and through G draw H F perpendicular to A B in red, or any coloured ink. At either of the points B or A, draw as at A the line A D perpendicular to A B. From A as a centre, describe in red ink an arc D K, of 3 or 4 inches radius, according to the radius of the protractor to be used in dividing it. Divide the arc by plotting off the degrees from the protractor into 120°, the zero being made to coincide with the line A D, and 90° with the line A B.

Now, if it be wished to protract a point which we may call Z from which the angle subtended by the stations A and

B was observed to be 45°, it is only necessary to apply a ruler to the point A passing through the division 45° on the divided arc, and cutting the line G F in F. Then F will be the centre of a circle, from which, with the radius F A or F B, describe the arc *o p* in which the point Z must be. If the same operation be performed with an adjacent station line B C, to which an angle has been taken from Z, the same result will be obtained, namely, an arc *r s*, in which the point must be found intersecting the arc *o p* in Z, the point required. If the observed angle be 90°, then the point G will be the centre of the circle in the circumference of which (with G A as radius) the point is to be found. If it exceed 90°, and be, for example, 110°, then a ruler applied at A, and passing through the division 110° on the arc, will cut the perpendicular F G in H, and H will be the centre of the circle in the circumference of which (with the radius H A) the point required must lie.

The only objection which can be urged against the adoption of this mode of protracting extensive surveys, in which many observations have been made, consists in the wearing and cutting up of the paper on which the plan is plotted, by drawing on it the numerous graduated protractors and straight lines required in the process, and by sweeping the arcs of the circles, the intersections of which are to determine the positions of the points of observation. When the protractors have been drawn on the paper, the work may be laid down much more quickly in the manner described than by using the station pointer, the difficulty of obtaining a nice coincidence of the arms of that instrument with the points observed being a constant source of deten-

tion, even although a needle be fixed at one of the stations to facilitate that part of the operation. Under all circumstances, however, the employment of the station pointer is recommended as that which is, generally speaking, found to be the most convenient method of protracting sextant observations; and in cases where it cannot be applied on account of the smallness of the scale, or the proximity of the points to be protracted to the observed stations, the method which I have just described may be beneficially employed;—an ivory or a brass protractor being used in such cases to lay off the observed angles, the graduation of the arc of a circle for that purpose being necessary only when the number of angles to be laid down is great.

Having described generally the method of protracting sextant observations, I shall now make a few brief remarks regarding the protraction of the sand banks and soundings.

The method of laying down the outlines of the low water channel and sand banks, a part of the work which ought to be completed before the protraction of the soundings is commenced, is so simple and obvious as to require almost no explanation. The different prominent points in the outlines, which have been fixed in the manner shewn in Plate X. and explained at page 75, are to be laid down in either of the ways just described, and the intervening lines carefully traced in from the field book; as exact a representation of the outline being made as the memory of the surveyor, aided by his field sketches, will admit of. The manner in which sand banks are represented on the finished plan will be seen on referring either to the chart of the

Lune or to Plate I., on both of which several of them are shewn.

It will be recollected that, in treating of the mode of sounding, two sorts of soundings were alluded to, the first being those which are taken throughout the area of the estuary during flood or ebb tide, and the second those taken in the navigable channel at low water. The soundings belonging to the first class are to be reduced to the high water of ordinary spring tides by the formula given at page 58; those of the second, or low water series, require no reduction. After the sand banks and low water channel have been protracted, the whole of these depths are to be laid down, their positions being determined by protracting the angles taken for that purpose. When this has been done, we shall have the high water soundings distributed over the several sand banks throughout the area of the estuary, and also a line of low water soundings in the centre of the navigable channel; but it is still necessary to ascertain the heights of the sand banks above low water. For this purpose, the rise of the tide at different parts of the river must be ascertained; which, together with the determination of the height of the sand banks above the low water mark, is done in the following manner.

From the system followed in taking the soundings which is described in Chapter IV., it is evident that a high and a low water sounding nearly corresponding in position, can generally be obtained at all the places where lines of soundings cross the low water channel, as will be easily understood by referring to the chart of the Lune, on which a few of the soundings have been laid down, although, from

the smallness of the scale, the exact lines in which they were taken, are not very definitely exhibited. Let α, therefore (without reference to the plate), represent a high water sounding (corrected by the formula given at page 58) whose position is in the navigable channel, and let β be the low water sounding which most nearly coincides with the position of α. Then $\alpha - \beta$ will be the vertical rise of tide (which we shall call γ) at that point. The values of γ being thus found at as many points as possible in the channel of the river, the number of which points will be limited by the number of the lines of high water soundings that cross the low water channel, they should be marked on the plan in large figures, as shewn in the chart of the Lune already referred to. Now, the values of the soundings $\alpha\,\alpha\,\alpha$, &c. distributed throughout the estuary, will either be equal to, greater, or less, than those of $\gamma\,\gamma\,\gamma$, &c., which we may suppose to represent the vertical rise of tide at the points nearest which the soundings occur, and the three results may be expressed as follows, when

$$\gamma - \alpha = n,$$

the sounding has occurred in the navigable channel or some deep pool in the sand banks, and n = the depth at low water; when

$$\gamma = \alpha,$$

the sounding has been made exactly at the edge of low water, or perhaps of a pool on a level with low water, as the case may be; or, in other words, at the point where the level of low water cuts the sand bank; and when

$$\alpha - \gamma = -\,n,$$

the sounding has occurred on a sand bank or other raised obstruction, and $-\,n$ = the height of the bank above low

water. In marking these soundings on the plan, it is necessary to shew the depths both at high and at low water, and the most convenient way of doing this is, to put them in a fractional form, the depths at high water being placed as the numerator, and those at low water as the denominator, distinguishing the heights of the sand banks above low water, by prefixing the negative sign. According to this notation, the three results alluded to would be stated thus on the plan:—

$$\frac{a}{n}, \quad \frac{a}{o}, \quad \text{or} \quad \frac{a}{-n},$$

according as the sounding had been taken in the low water channel, at its edge, or on the top of a sand bank.

For an example of this, Plate I. may be referred to, in which a few soundings have been laid down, simply for the purpose of illustrating the subject more fully. Opposite Flisk station, it will be observed, by the large figures in the middle of the channel, that the rise of tide is 14 feet 6 inches. It will also be seen that, at the middle of the channel, the sounding $\frac{31^{\text{ft.}}\ 1^{\text{in.}}}{16^{\text{ft.}}\ 7^{\text{in.}}}$ occurs, which denotes the depth at high water to be 31 feet 1 inch, and that at low water 16 feet 7 inches, the difference between the two quantities being 14 feet 6 inches, which is the rise of tide at that place. On approaching the sand bank, the sounding $\frac{14^{\text{ft.}}\ 10^{\text{in.}}}{0^{\text{ft.}}\ 4^{\text{in.}}}$ occurs, signifying the depth to be 14 feet 10 inches at high, and 4 inches at low water, and the first sounding on the bank is $\frac{11^{\text{ft.}}\ 8^{\text{in.}}}{-2^{\text{ft.}}\ 10^{\text{in.}}}$, denoting the depth at high water to

be 11 feet 8 inches, and the height of the sand bank above the level of low water to be 2 feet 10 inches. The same notation will be perceived throughout the whole of the chart of the Lune.

The only subject connected with the protraction which seems to call for further remark, is that of making a longitudinal section of the bed and low water line of a river. This may be done by assuming, as in ordinary cases, a level datum line, in reference to which all the heights must be protracted. The line of high water, on which there is, generally speaking, a rise from the mouth of the river upwards, should be accurately laid down, in reference to the horizontal datum line, from the results of the tide observations. The rise of the tide at different points, as protracted on the plan when laid off from the line of high water, gives a section of the surface of low water, and the low water soundings taken in the centre of the channel, when laid off from the line of low water, give the section of the bottom of the river; and thus, if the work be correctly done, all the elements of a near approximation to a true section of the river are obtained. The longitudinal section shewn in the chart of the Lune illustrates the style in which the section ought to be drawn, although, owing to the smallness of the scale, the details of the heights and distances, which appear on the original, were necessarily omitted.

NOTE RELATIVE TO THE CHART OF THE RIVER LUNE.

It has been considered necessary to lay before the reader an example of a marine survey for engineering purposes, made on the principles, and in accordance with the recommendations, contained in the preceding treatise, for the purpose of imparting distinct ideas as to the manner in which the several departments of the survey appear, when represented in a plan. I have therefore selected a survey of limited extent, that the different parts of it might be exhibited on a scale sufficiently large to render the example given both intelligible and useful; and, in order to approximate to the appearance presented by a manuscript chart, the style of engraving and colouring has been made to resemble as nearly as possible the drawing of the original plan.

The example alluded to is placed at the commencement of this volume, and is a chart of part of the river Lune, in Lancashire, from a survey made in the year 1838, in reference to the improvement of its navigation.

In noticing this Plate, it is necessary to state, that, from the smallness of its scale, the work contained in it is not by any means that which was actually performed, or was

required for forming designs of improvement, a limited selection only having been made to suit the reduced scale of the engraving; but, nevertheless, it is believed that every thing has been inserted that is essential to render it useful as a guide in constructing plans. The scale on which the original plan was protracted was 15 inches, whereas the scale of the reduced engraving is only $3\frac{1}{2}$ inches, to the statute mile.

It may be proper to remark in this place, that the selection of a scale for plans is a matter of much importance in all Parliamentary business, the requirements of the Houses of Lords and Commons being most strict and particular on that and many other points in which the engineer is interested. They specify, for example, as is well known, that all plans are to be drawn to a scale of not less than 4 inches to the mile, that all sections are to be drawn to the same longitudinal scale as the plan, and to a vertical scale of not less than 1 inch to every 100 feet, and that lands to be taken for the use of proposed works are, under certain circumstances, to be represented on the plan on an enlarged scale of not less than one quarter of an inch to every 100 feet. As it is not my intention, however, to enter on these various requirements, I have appended to this treatise an abstract of the parts of the standing orders of the Houses of Lords and Commons, relating to those bills with which the particular system of surveying that has been described is directly connected, as it may be useful, in absence of more full information on the subject, to those surveying or preparing plans with reference to Parliamentary proceedings.

To return to the chart of the Lune, which is not given as

a specimen of a parliamentary but of an engineering plan, it will be seen, from the following description, that it embraces the different departments of surveying which have been described, and for convenience, the pages of the treatise at which they are referred to, are noted on the margin. It includes that part of the river which extends from Lancaster Bridge to Glasson Dock, and exhibits the state of the navigation at low water, the whole of the sand banks being left dry. The state of the river and estuary at high water, however, may be ascertained by an examination of the depths marked on the plan. These are explained in the references noted on the chart in the following words.

See Treatise. Page 151. "The large figures at the edge of the low water channel, indicate the rise of tide at the points where they occur at Page 56. high water of an ordinary spring tide rising 21 feet at Glasson.

Page 152. "The soundings or depths of water are marked in a fractional form. The figures in the place of the numerator re- Page 58. present the depths at high water. Those in the place of Pages 68 and 152. the denominator which have not the negative sign prefixed to them represent the depths at low water; but where the Page 152. negative sign is prefixed they indicate the height of the sand banks above low water."

From an examination of these figures, it is evident that the depth at high and low water, and the heights of the sand banks above low water, can be at once ascertained.

Page 56. It will be perceived that the whole of the soundings and the heights of the sections are referred to the level of high water of an ordinary spring tide, rising 21 feet at Glasson, as the datum line. This line was adopted in the case of the

Lune, as the high water line was found to be very nearly on the same level at Lancaster, Heaton, and Glasson. But in cases when the high water line is not level, a datum line is Page 153. of course adopted, from which the line of high water is laid off in the same manner as that of low water or the bed of the river.

The Longitudinal Section, from the smallness of the scale, is restricted to that part of the river between Lancaster Bridge and Colleway, being the part of the navigation which required most improvement.

The parts coloured red on the plan, as at Scale and Baffler's fords, and Oxcliff, Heaton, and Colleway shoals, &c., do not dry, but are merely protuberances in the bed of the river which are proposed to be dredged.

They are shewn more distinctly on the section, the red coloured parts of which correspond to those of the same colour on the plan.

Ovangle, Heaton, Colleway, and the other lands represented as "marsh," are covered with water at high tides, and a series of levels was taken on each of them to ascertain which could, with most advantage, be used as a spoil bank on which to deposit the stuff excavated from the chan- Page 83. nel, and so be reclaimed from the estuary of the river and converted into arable land. The outlines of these marshes Page 90. were laid down by sextant observations.

The exact positions of all the prominent points on the banks of the river, such as Glasson, Basil, Overton, &c. Page 1. were determined by the triangulation, and the intermediate coast or bank of the estuary was surveyed by the traverse Page 84. system.

Page 37. Tide observations were made at Lancaster, Heaton, and Page 21. Glasson. The base line was measured on one of the Page 93. marshes. Borings and cross sections were also made at the different fords and shoals, but from the smallness of the scale it was considered unnecessary to shew them on the plan.

APPENDIX.

Abstract of the Standing Orders of the Houses of Lords and Commons with reference to giving Notices, and Constructing and Lodging Plans, in making application to Parliament for Bills for making, maintaining, varying, extending, or enlarging any Bridge, Turnpike Road, Cut, Canal, Reservoir, Aqueduct, Waterwork, Navigation, Tunnel, Archway, Pier, Port, Harbour, Ferry, or Dock. 1842.

1. *Notices of Application.*—That notices shall be given in all cases where application is intended to be made for leave to bring in a bill included under any of the heads above mentioned.

2. *Notices to be published.*—That such Notices shall be published in *three* successive *weeks* in the months of *October* and *November*, or either of them, immediately preceding the Session of Parliament in which Application for the Bill shall be made, in the *London, Edinburgh* or *Dublin Gazette*, as the case may be, and in some one and the same Newspaper of every County in which the City, Town or Lands to which such Bill relates shall be situate; or if there is no Newspaper published therein, then in the Newspaper of some County adjoining or near thereto, or if such Bill does not relate to any particular City, Town or Lands, in the *London, Edinburgh* or *Dublin Gazette* only, as the case may be; and that all Notices required to be inserted in the *London, Edinburgh* or *Dublin Gazette*

shall be delivered at the Office of the Gazette in which the insertion is required to be made, during the usual office hours, at least *Two* clear *Days* previous to the publication of the Gazette, and that the receipt of the Printer for such Notice shall be proof of its due delivery.

3. *Intention to levy or alter Tolls to be stated.*—That if it be the intention of the Parties applying for leave to bring in a Bill, to levy any Tolls, Rates or Duties, or to alter any existing Tolls, Rates or Duties, or to vary any other rights or privileges, the Notices shall specify such intention.

4. *Notice to be affixed on Doors of Sessions House at the Session preceding the Meeting of Parliament. In Scotland, on Doors of Parish Churches in October and November.*—That all Notices shall also be given at the General Quarter Session of the Peace which shall have been holden for every and each County, Riding, or Division, in or through which the work shall be made, maintained, varied, extended or enlarged, at Michaelmas or Epiphany preceding the Session of Parliament in which such application is intended to be made, by affixing such Notice on the Door of the Session House of each and every such County, Riding, or Division, where such General Quarter Session shall be holden; save and except as to any Bill for such purposes in Scotland; in which case, instead of affixing such Notices on the door of the Session House, such Notices shall be written or printed on paper, and affixed to the Church door of the Parish or Parishes in or through which such work is intended to be made, maintained, varied, extended, or enlarged, for two Sundays in each of the months of October and November immediately preceding the introduction into Parliament of the Bill for which such application is intended to be made.

5. *Notices to contain Names of Parishes, &c.*—That all Notices shall contain the Names of the Parishes, Townships and extra-parochial places from, in, through, or into which the Work is intended to be made, maintained, varied, extended, or enlarged, and shall state the time and place of deposit of the Plans, Sections, and Books of Reference, respectively, with the Clerks of the Peace,

Parish Clerks, Schoolmasters, Town Clerks, and Postmasters, as the case may be.

6. *Plans, &c. with Clerk of the Peace.*—That a Plan, and also a duplicate of such plan, on a scale of not less than Four Inches to a Mile, exhibiting thereon the height of the several embankments and the depth of the several Cuttings on a scale specified thereon, with a Section and Duplicate thereof as hereinafter described, be deposited for public inspection at the office of the Clerk of the Peace for every County, Riding, or Division in *England* or *Ireland*, or in the Office of the principal Sheriff Clerk of every County in *Scotland*, in or through which the work is proposed to be made, varied, extended, or enlarged, on or before the 30th day of *November* immediately preceding the Session of Parliament in which application for the Bill shall be made; which Plans shall describe the line or situation of the whole of the Work, and the Lands in or through which it is to be made, maintained, varied, extended, or enlarged, or through which every communication to or from the Work shall be made, together with a Book of Reference containing the Names of the Owners, or reputed Owners, Lessees or reputed Lessees, and Occupiers of such Lands respectively.

7. *Lands within Deviation to be on Plan. Buildings, &c. on enlarged Scale.*—That where it is the intention of the parties to apply for powers to make any lateral deviation from the line of the proposed Work, the limits of such deviation shall be defined upon the Plan, and all Lands included within such limits shall be marked thereon, and that in all cases, an additional Plan of any Building, Yard, Court-Yard, or Land within the curtilage of any Building, or of any Ground cultivated as a Garden, either on the original line or included within the limits of the said deviation, shall be laid down on the said Plan or on the additional Plan deposited therewith, upon a scale of not less than a *quarter* of an *inch* to every 100 feet.

8. *Section.*—That the Section shall be drawn to the same hori-

zontal scale as the Plan, and to a vertical scale of not less than *one inch* to every 100 feet, and shall shew the surface of the ground marked on the Plan, and the intended level of the proposed Work, and a datum horizontal line, which shall be the same throughout the whole length of the work, or any Branch thereof respectively, and shall be referred to some fixed point stated in writing on the Section near either of the Termini.

9. *Clerks of Peace to indorse a Memorial on Plans, &c.*—That the Clerks of the Peace or Sheriff-Clerks, or their respective Deputies, do make a Memorial in writing upon the Plans, Sections, and Books of Reference so deposited with them, denoting the time at which the same were lodged in their respective offices, and do at all seasonable hours of the day permit any person to view and examine one of the same, and to make copies or extracts therefrom; and that *one* of the two plans and Sections so deposited, be sealed up and retained in the possession of the Clerk of the Peace or Sheriff-Clerk until called for by order of one of the two Houses of Parliament.

10. *Plan and Section with Parish-Clerk, &c.*—That on or before the 31st day of *December*, a copy of so much of the said Plans and Sections as relates to each Parish in or through which the Work is intended to be made, maintained, varied, extended, or enlarged, together with a book of Reference thereto, shall be deposited with the parish Clerk of each such parish in *England*, the Schoolmaster of each such parish in *Scotland* (or in Royal Burghs with the Town Clerk,) and the Postmaster of the Post-town in or nearest to such Parish in *Ireland*.

11. *Time for Deposit in Private Bill Office.*—That on or before the 31st day of *December*, a copy of the said Plans, Sections, and Books of Reference, shall be deposited in the Private Bill Office for the Commons, and in the Office of the Clerk of the Parliaments for the Lords.

12. *Estimate and Subscription Contract.*—That an Estimate of the Expense be made and signed by the person making the same,

and that a Subscription be entered into under a Contract, to *three-fourths* the amount of the Estimate.

13. *Cases wherein Declaration may be substituted for Subscription Contract.*—That in cases where the Work is to be made by means of Funds, or out of Money to be raised upon the credit of present Surplus Revenue, under the control of Directors, Trustees, or Commissioners, as the case may be, of any existing Public Work, a Declaration stating those facts, and setting forth the Particulars of such control, and the Nature and Amount of such Funds or Surplus Revenue, and given under the common seal of the Company, or under the hand of some authorized Officer of such Directors, Trustees, or Commissioners, may be substituted in lieu of the Subscription Contract, and in addition to the estimate of the expense.

14. *Cases wherein Declaration and Estimate of amount of Rates may be substituted for Subscription Contract.*—That in cases where the Work is to be made out of Money to be raised upon the Security of the Rates and Duties to be created by any Bill, under which no private or personal pecuniary profit or advantage is to be derived, a Declaration stating those facts, and setting forth the means by which Funds are to be obtained for executing the Work, and signed by the Party or Agent soliciting the Bill, together with an Estimate of the probable Amount of such Rates and Duties, signed by the Person making the same, may be substituted in lieu of the Subscription Contract, and in addition to the estimate of the expense.

15. *Contract to contain Christian and Surnames of Parties.*—That all Subscription Contracts shall contain the Christian and Surnames, Description and Place of Abode, of every Subscriber; his Signature to the amount of his Subscription, with the amount which he has paid up; and the Name of the Party witnessing such Signature, and the date of the same respectively; and that it be proved to the satisfaction of the Committee on Petitions that a sum equal to *one-tenth* part of the amount subscribed has been deposited

with the Court of Exchequer in *England*, if the work is intended to be done in *England*, or with the Court of Exchequer either in *England* or *Scotland*, if such work is intended to be done in *Scotland*, and with the Court of Chancery in *Ireland*, if such work is intended to be done in *Ireland*; and that not less than *three-fourths* in number of the Subscribers shall have paid up their Shares of such Deposit.

16. *Not valid unless entered into subsequent to close of previous Session.*—That no Subscription Contract shall be valid unless it be entered into subsequent to the close of the Session of Parliament previous to that in which application is made for leave to bring in the Bill to which it relates, and unless the Parties subscribing to it bind themselves, their Heirs, Executors, and Administrators, for the Payment of the Money so subscribed.

17. *To be printed at expense of promoters of Bill.*—That previous to the presentation of a Petition for the Bill in the Commons, and the second reading in the Lords, copies of the Subscription Contract, with the Names of the Subscribers arranged in alphabetical order, and the amount of the Deposit respectively paid up by each such Subscriber, or where a Declaration and Estimate of the probable amount of Rates and Duties are substituted in lieu of a Subscription Contract, Copies of such Declaration, or of such Declaration and Estimate, be printed at the expense of the Promoters of the Bill, and be delivered at the Vote Office of the clerk of the Parliament, for the use of the Members of the respective Houses.

18. *Application to be made to Owners, List of Assents, &c.*—That on or before the 31st day of December immediately preceding the Application for a Bill by which any Lands or Houses are intended to be taken, or an extension of the time granted by any former act for that purpose is sought for, Application in writing be made to the Owners or reputed Owners, Lessees or reputed Lessees, and Occupiers, either by delivering the same personally, or by leaving the same at their usual place of abode, or, in their absence from the United Kingdom, with their Agents respectively,

of which Application having been duly made, the production of a written acknowledgment by the party applied to of the receipt of such Application, shall be sufficient evidence, in the absence of other proof, of the same having been duly delivered or left as aforesaid; and that separate lists be made of the Names of such Owners, Lessees, and Occupiers, distinguishing which of them have assented, dissented, or are neuter in respect thereto.

19. *Application to be made to Owners, &c., when the Bill is to abridge the extent of any Public Work.*—That before any Application is made to the House for a Bill whereby any part of a Work authorized by any former Act is intended to be relinquished, Notice in writing of such Bill be given to the Owners or reputed Owners and Occupiers of the lands in which the part of the said Work intended to be thereby relinquished is situate.

20. *When it is intended to divert Water from an existing Cut, &c., into an intended Cut, &c., the name of the existing Cut, &c., to be mentioned.*—That in all cases where it is proposed to divert into any intended Cut, Canal, Reservoir, Aqueduct, or Navigation, or into any intended variation, extension, or enlargement thereof respectively, any water from any existing Cut, Canal, Reservoir, Aqueduct, or Navigation, whether directly or derivatively, and whether under any agreement with the Proprietors thereof, or otherwise, the notices shall contain the name of every such existing Cut, Canal, Reservoir, Aqueduct, or Navigation, the waters supplying which by virtue of any Act of Parliament, will either directly or derivatively, flow or proceed into any such intended Cut, Canal, Reservoir, Aqueduct, or Navigation, or into any intended variation, extension or enlargement thereof.

21. *Plan to describe Brooks, &c., to be diverted.*—That in all cases where it is proposed to make, vary, extend, or enlarge any Cut, Canal, Reservoir, Aqueduct, or Navigation, the Plan shall describe the Brooks and Streams to be directly diverted into such intended Cut, Canal, Reservoir, Aqueduct, or Navigation, or into any variation, extension, or enlargement thereof respectively, for supplying the same with Water; it shall also exhibit the height

of the several embankments, and the depth of the several Cuttings respectively, on a scale specified thereon; and in cases of Bills for improving the navigation of any River, there shall be a Section which shall specify the Levels of both Banks of such River, and where any alteration is intended to be made therein shall describe the same by feet and inches.

22. *Plans, &c. to be lodged.*—That all Plans, Sections, Books of Reference, Lists of Owners and Occupiers, Estimates and Copies of the Subscription Contracts, required by the Standing Orders of the House, be lodged in the Private Bill Office; and that the receipt thereof be acknowledged accordingly, by one of the Clerks of the said Office, upon the said Documents, and upon the Petition, before it is presented.

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